ENVIRONMENTAL RESTORATION PROJECT

A Department of Energy
Environmental Cleanup Program

LA-13893-MS
February 2002
ER2001-0960

Characterization Well R-22 Completion Report

Los Alamos
NATIONAL LABORATORY
Los Alamos NM 87545

Produced by the Groundwater Investigations Focus Area

TABLE OF CONTENTS

Appendixes

List of Figures

List of Tables

List of Acronyms and Abbreviations

API	American Petroleum Institute
AR	air rotary
ASTM	American Society for Testing and Materials
bgs	below ground surface
BUS	Business Operations
CME	Central Mine Equipment
DOC	Dissolved organic carbon
DOE	Department of Energy
DR	Dual Rotary
DTH	Down-the-Hole Hammer
DTW	depth to water
DX	Dynamic Experimentation
ECS	Elemental Capture Survey
EDL	estimated detection limit
EES	Earth and Environmental Sciences
Eh	oxidation potential
EM&R	Emergency Management and Response
EPA	Environmental Protection Agency
ER	Environmental Restoration
ESH	Environmental Safety and Health
FAPL	focus area project leader
FIP	field implementation plan

FMU	Facility Management Unit
FPL	field project leader
FSF	field support facility
FTL	field team leader
FTM	field team manager
GC/MS	Gas Chromatography Mass Spectrometry
GIT	Groundwater Integration Team
GPS	Global Positioning System
HASP	health and safety plan
HE	high explosive
HPLC	high pressure liquid chromatography
HSA	hollow-stem auger
HWFP	Hazardous Waste Facility
IC	ion chromatography
ICPMS	Inductively coupled plasma mass spectrometry
I.D.	inner diameter
IRMS	isotope ratio mass spectrometry
KPA	kinetic phosphorimetric analysis
LANL	Los Alamos National Laboratory
LOI	loss on ignition
Ma	mega annum (radiometric age in millions of years)
MCL	Maximum
MOU	memorandum of understanding
MP	multiport
MSCT	mechanical sidewall-coring tool
MWIP	Monitoring Well Installation Project
NAD	North America Datum
NGR	natural gamma radiation
NMED	New Mexico Environment Department
NOI	notice of intent
NTU	nephelometric turbidity units
O.D.	outer diameter
PAHs	polycyclic aromatic hydrocarbons
PCBs	polychlorinated biphenyls
pH	A measure of acidity/alkalinity
PMC	Project Management Company
PPE	personal protective equipment
PVC	polyvinyl chloride
QA	quality assurance
QXRD	quantitative x-ray diffraction

Rb	rubidium
RC	Reverse Circulation (rods)
RDX	royal demolition explosive
RLWTF	Radioactive Liquid Waste Treatment Facility
RSP	radiological screening personnel
SAP	sampling and analysis plan
SMO	Sample Management Office
SOP	standard operating procedure
Sr	strontium
SSHASP	site specific health and safety plan
SSO	site safety officer
SVOC	semivolatile organic compound
TA	Technical Area
TD	total depth
TL	Team Leader
TNT	trinitrotoluene
TOC	total organic carbon
VOC	Volatile organic compound
WCSF	Waste Characterization Strategy Form
WGII	Washington Group International, Incorporated
XRD	x-ray diffraction
XRF	x-ray fluorescence

Metric to English Conversions

Multiply SI (Metric) Unit	by	To Obtain US Customary Unit
kilometers (km)	0.622	miles (mi)
kilometers (km)	3281	feet (ft)
meters (m)	3.281	feet (ft)
meters (m)	39.37	inches (in.)
centimeters (cm)	0.03281	feet (ft)
centimeters (cm)	0.394	inches (in.)
millimeters (mm)	0.0394	inches (in.)
micrometers or microns (µm)	0.0000394	inches (in.)
square kilometers (km^2)	0.3861	square miles (mi^2)
hectares (ha)	2.5	acres
square meters (m^2)	10.764	square feet (ft^2)
cubic meters (m^3)	35.31	cubic feet (ft^3)
kilograms (kg)	2.2046	pounds (lb)
grams (g)	0.0353	ounces (oz)
grams per cubic centimeter (g/cm^3)	62.422	pounds per cubic foot (lb/ft^3)
milligrams per kilogram (mg/kg)	1	parts per million (ppm)
micrograms per gram (µg/g)	1	parts per million (ppm)
liters (L)	0.26	gallons (gal.)
milligrams per liter (mg/L)	1	parts per million (ppm)
degrees Celsius (°C)	9/5 + 32	degrees Fahrenheit (°F)

CHARACTERIZATION WELL R-22 COMPLETION REPORT

by

Ted Ball, Mark Everett, Patrick Longmire, David Vaniman, William Stone, David Larssen, Keith Greene, Ned Clayton, Steve McLin

ABSTRACT

Characterization well R-22 is located atop the mesa separating Cañada del Buey and Pajarito Canyon in Los Alamos County, New Mexico. It is east of the waste disposal facility at Technical Area (TA)-54, Los Alamos National Laboratory (also known as "the Laboratory" and LANL). This characterization well is the seventh of approximately 32 wells to be installed in the regional aquifer as part of the Laboratory's "Hydrogeologic Workplan" (LANL 1998, 59599). R-22 was funded and installed by the Laboratory's Environmental Restoration (ER) Project. The well was designed primarily to provide water-quality and water-level data for potential intermediate-depth perched zones and for the regional aquifer downgradient of the waste disposal facility at TA-54. R-22 was also designed to collect geologic, hydrologic, and geochemical data that contribute to the understanding of the vadose zone and regional aquifer in this part of the Laboratory. In the Hydrogeologic Workplan, R-22 was originally planned for installation in Pajarito Canyon, but its location was moved to the mesa top to be closer to and more directly downgradient of TA-54.

R-22 was drilled in two phases. Phase I was conducted during August 2000 and consisted of using a hollow-stem-auger method to drill to a depth of 47 ft for installation of surface casing within the Tshirege Member of the Bandelier Tuff. Phase II was conducted from September to October 2000. Drilling methods included using a tri-cone bit, a downhole percussion hammer, and dual-wall casing to drill both casing advance and open hole. During Phase II, R-22 was drilled to a depth of 1489 ft, and a multiscreen well containing five screened intervals was installed.

Geologic units encountered in R-22 consisted of, in descending order, ash flows of the Tshirege Member and Otowi Member of the Bandelier Tuff including the basal Guaje Pumice Bed, lavas, cinder units, interflow units, and subflow deposits of the Cerros del Rio volcanic field, an upper sequence of fanglomerate deposits of the Puye Formation, an older basalt, and a lower sequence of fanglomerate deposits of the Puye Formation. The most notable difference between the predicted and as-found stratigraphy was the greater thickness of the Cerros del Rio volcanic sequence. Also notable were the absence of Puye Formation axial river gravels and the absence of Santa Fe Group sediments within the depth drilled.

Three zones of saturation were anticipated at R-22; two were perched zones, and one was the regional zone of saturation. However, no water was encountered until a depth of approximately 890 ft. This water was believed to be associated with the regional zone of saturation. Saturation continued to the total depth of the borehole (1489 ft). Five well screens were distributed through the regional zone of saturation. Straddle-packer/slug-injection tests were performed on four screened intervals (screens 2, 3, 4, and 5). Hydraulic conductivities ranged from 0.27 ft/d for screen #2 to 2.32 ft/d for screen #3.

Extensive borehole geophysical data were obtained from two sources—support subcontractor personnel who conducted borehole video and natural gamma radiation surveys using the Laboratory's logging trailer, and Schlumberger, Inc., which obtained a suite of borehole geophysical logs. These surveys were conducted in cased hole from the surface to a depth of 1330 ft and in open hole below 1330 ft. Open-hole

geophysical logging included caliper, resistivity, natural gamma radiation, spontaneous potential, lithodensity, magnetic resonance, borehole color video, epithermal neutron, neutron porosity, and spectral natural radiation (potassium, uranium, and thorium).

Samples of groundwater from two depths (883 ft and 1489 ft) were collected during drilling. These samples were characterized for major anions, volatile organic compounds, high explosives, semivolatile organic compounds, radionuclides, and stable isotopes. Methods recommended by both the Environmental Protection Agency (EPA) and the Laboratory were followed for analysis of groundwater. Groundwater from the upper zone contained concentrations of bicarbonate (120 milligrams per liter[mg/L]), chloride (21 mg/L), fluoride (1.19 mg/L), oxalate (1.06 mg/L), and sulfate (16 mg/L). It also contained tritium at an activity of 109 picoCuries per liter(pCi/L). Americium-241, plutonium-238, plutonium-239,240, and strontium-90 were at levels less than detection. Activities of uranium-234, uranium-235, and uranium-238 were 1.48, 0.126, and 1.41 pCi/L, respectively. The water sample collected at 1489 ft was analyzed for nitrogen isotopes. It had a $\delta^{15}N(NO_3)$ value of +9.6 permil.

1.0 INTRODUCTION

This report describes the drilling and testing activities for characterization well R-22. R-22 was funded and installed by ER. The report is organized into two parts. Part I describes all the operational activities involved in installing groundwater monitoring well R-22. Part II presents the results from analysis of rock and water samples and an interpretation of the geologic, geophysical, hydrologic, and geochemical conditions encountered in the borehole.

R-22 is located atop the mesa separating Cañada del Buey and Pajarito Canyon, east of the waste disposal facility at TA-54. R-22 was drilled to a depth of 1489 ft, and was completed as a multiscreen well containing five screened intervals that can be sampled individually. It is the seventh characterization well drilled to the regional aquifer as part of the "Hydrogeologic Workplan" (LANL 1998, 59599) in support of the "Groundwater Protection Management Program Plan" (LANL 1996, 70215) of the Laboratory.

R-22 is primarily designed to provide water quality and water-level data for potential intermediate-depth perched zones and for the regional aquifer downgradient of TA-54. In the hydrogeologic work plan, R-22 was originally planned for installation in Pajarito Canyon, but its location was moved to the mesa top so that it would be closer to TA-54 and better suited for a future monitoring well.

Although R-22 is primarily a characterization well, its design also meets the requirements of a monitoring well as defined in Module VIII of the Laboratory's Hazardous Waste Facility Permit (HWFP). Incorporation of this well into a Laboratory-wide groundwater monitoring program will be evaluated at a later date when the results of this characterization activity are integrated with groundwater investigations in the Hydrogeologic Workplan (LANL 1998, 59599).

PART I: SITE ACTIVITIES

2.0 PREPARATION

Preparation activities at R-22 included administrative preparation and site preparation. A graphic depiction of project history to accompany the text below is presented in Appendix A. Appendix B compares planned and actual activities at the site. The following text sections are arranged in chronological order.

Preparatory work for drill-hole R-22 occurred over a period of approximately four months. This timespan included preparation of the statement of work and the field implementation plan.

2.1 Administrative Preparation

Washington Group International, Incorporated, (WGII) received contractual authorization to start administrative preparation tasks on July 12, 2000. As part of this preparation WGII developed a Site-Specific Health and Safety Plan (SSHASP) for all entities involved in R-22 work. WGII also prepared the R-22 Waste Characterization Strategy Form (WCSF). The Laboratory prepared the field implementation plan which outlined drilling and sampling plans for R-22 to guide field personnel in the execution of field activities. The host facility, Facility Management Unit (FMU)-64 (TA-54), implemented a memorandum of understanding (MOU) with ER, in lieu of a Facility Tenant Agreement to provide access and security control for the R-22 project.

The completeness of all administrative documents, permits, agreements, and plans was reviewed at an ER Readiness Review Meeting on August 10, 2000. The Groundwater Investigations Focus Area project leader signed the Readiness Review Checklist on August 15, 2000, giving authorization to begin field work.

2.2 Site Preparation

On August 17, 2000, site preparation work began at the R-22 site. SG Western Construction prepared the drilling site under the direction of WGII. Initially, the site was cleared using a bulldozer. A pit was then excavated for the drill cuttings and lined with plastic. The site was graded and leveled; base course was spread over the site and compacted; and the jack cellar was dug and cement poured in the cellar floor. The site was fenced for access control, and office trailers were brought to the site. Site preparation activities were completed on August 30, 2000.

3.0 DRILLING

Drilling of R-22 was conducted in two phases. Phase I was drilled by Stewart Brothers Drilling, Inc. (Stewart), and Phase II was drilled by Dynatec Drilling Company (Dynatec). Phases I and II are described in greater detail below. Drilling shift information is given in Table 3.0-1. Performance statistics for R-22 are given in Table 3.0-2.

Table 3.0-1
Drilling Shift Information

Operations Category	Dates	Number of Shifts
Phase I drilling/site preparation/rig mobilization	August 17 – August 21, 2000	3 12-hr
Phase II drilling	September 8 – October 11, 2000	57 12-hr[a]
Geophysics/well design	October 12 – October 16, 2000	5 12 hr
Well installation	October 17 – October 19, 2000	4 12-hr
Insertion of annular fill	October 20 – November 3, 2000	28 12-hr
Well development/hydrologic testing	November 4 – November 19, 2000	30 12-hr
Westbay™ installed	December 6 – December 8, 2000	3 12-hr
Surface completion/site restoration tasks	December 4, 2000 – March 2001	15 12-hr
Total shifts	August 17 – March 2001	145 12-hr

[a] Includes time modifying stabilizer.

Phase I was drilled using a 10 1/2-in.-outer diameter (O.D.) hollow-stem auger (HSA). Stewart Brothers Drilling, Inc., augered the pilot hole with a Central Mine Equipment (CME)-750 drill rig, and then over-reamed with a 21-in.-O.D. HSA to 47 ft.

During Phase II, Dynatec used a Foremost Dual Rotary (DR)-24 drill rig. Final well development and hydrologic testing were also completed using the Foremost drill rig. Dynatec provided three-man drilling crews, crew vehicles, drill hammers, dual-wall rod systems, a 1-ton flatbed truck, water trucks, and a 10-ton boom truck for handling casing, drill pipe, and heavy support apparatus such as casing jacks.

The ER Project's Field Support Facility (FSF) provided drill casings, drilling bits, a small front-end loader, the dust suppression system, field support trailers (including logging and sampling trailers), water containment tanks, drums for cuttings management, a Hermit data logger and pressure transducers, a depth-to-water meter, water sampling bailers, a diesel-powered electric generator, and water-sample testing and filtering apparatus. The Laboratory's geology and geochemistry group (Earth and Environmental Sciences [EES]-1) provided a core-logging microscope. Environment, Safety and Health Division (ESH)-18 provided a geophysical logging trailer.

Table 3.0-2
Performance Statistics for R-22

Drilling Types	Hollow Stem Auger	18-in. Casing	Open Hole Tricone (16-in.)	Open Hole DTH[a] (16-in.)	Casing Advance 14¼-in. Under Reamer 13.375-in. Casing	Open-Hole DTH[a] (12.25-in.)	Casing Advance and Open-Hole DTH[a] (10.5-in.)	9.625-in. Casing	7-in. Reverse Circulation (RC) rods	Total (ft)[b]
Total footage drilled (ft)	47	n/a[c]	148	18	316	748	329	1330	1442	1489
Total footage rate (ft/hr)	35.3	n/a	11.0	4.6	6.1	11.8	6.7	10.0	9.0	9.0
Basalt footage (ft)[d]	n/a	n/a	n/a	18	261	641	122	n/a	1042	1042
Basalt rate (ft/hr)[d]	n/a	n/a	n/a	4.6	6.1	12.0	6.7	n/a	8.8	8.8
Puye clastics footage (ft)	n/a	n/a	n/a	n/a	n/a	105	77	12	182	182
Puye clastics rate (ft/hr)	n/a	n/a	n/a	n/a	n/a	10.6	6.6	10.0	8.4	8.4
Bandelier footage (ft)[e]	47	n/a	148	n/a	n/a	n/a	n/a	n/a	148	195
Bandelier rate (ft/hr)[e]	35.3	n/a	11.0	n/a	n/a	n/a	n/a	n/a	11.0	13.2
Trip-in footage (ft)	n/a	46	n/a	n/a	511	n/a	n/a	671	5992.5	7220.5
Trip-in rate (ft/hr)	n/a	10.2	n/a	n/a	42.6	n/a	n/a	95.9	219.4	142.1
Trip-out footage (ft)	n/a	n/a	n/a	n/a	340	n/a	n/a	n/a	8434	8774
Trip-out rate (ft/hr)	n/a	n/a	n/a	n/a	28.3	n/a	n/a	n/a	266.1	200.7

Note: Performance statistics cover entire history of drilling.
[a] Down-The-Hole Hammer.
[b] Total depth (TD) of borehole is 1489 ft.
[c] n/a = not applicable.
[d] Includes Cerros del Rio and older basalts, and interflow deposits.
[e] Includes Tshirege and Otowi members; no Cerro Toledo present at this location.

3.1 Phase I Drilling

On August 18, 2000, the HSA rig drilled to a depth of 47 ft below ground surface (bgs) in preparation for setting the 18-in. (inner diameter [I.D.]) surface conductor casing. When crews returned to the site on August 19, 2000, the bottom of the hole was tagged at 40 ft bgs. The 18-in. conductor casing was inserted into the boring and pushed into the slough and soft tuff at the bottom of the boring, giving a 50-ft length of conductor casing with a 2-ft stickup. The conductor casing was then cemented around the outer annulus. Phase I drilling was completed on August 21, 2000.

3.2 Phase II Drilling

Air-rotary drilling commenced September 8, 2000. Fluid-assisted, air-rotary drilling was performed using the dual-wall reverse-circulation method. In the dual-wall reverse-circulation method, compressed air and drilling fluid are pumped down into the annular space located between the inner and outer drill-pipe walls. The returns come up the center pipe. Drilling fluid consisted of municipal water mixed with QUIK-FOAM® and EZ-MUD *plus*® polymers. The drilling fluid was added to the compressed-air circulation medium to help remove cuttings and stabilize the hole.

The borehole was advanced beneath the 18-in. conductor casing with a 16-in. tri-cone bit to 194 ft bgs. When the drilling operation encountered competent basalt at 194 ft bgs on September 10, the bit configuration was changed to a 16-in. down-hole hammer bit, and borehole advancement continued in this manner to 212 ft bgs. On September 12, 210 ft of 13 5/8-in. O.D. drill casing was installed in the borehole to help stabilize it.

After three days of adjustments to the stabilizer rod, drilling resumed on September 15 using a 12 1/4-in. down-hole hammer bit, advancing the borehole to 252 ft bgs. At this depth, drilling was hindered by lost circulation and an unstable and caving borehole in Cerros del Rio basalt, prompting a change to a casing advance method utilizing 13 5/8-in.-O.D. drill casing in tandem with a 14 1/2-in. under-reaming bit. This method entailed reaming the borehole with the 14 1/2-in. bit from 194 ft bgs to 252 ft bgs.

The 13 5/8-in.-O.D. drill casing was advanced to 510 ft bgs on September 24. It was reamed into basaltic rock at this depth to avoid having to set the casing into the less competent Puye formation, which was predicted to underlie the basalt closely at this depth.

Below the 13 5/8-in.-O.D. drill casing, the borehole was advanced open hole to 1258 ft bgs using a 12 1/4-in.-diameter down-hole hammer bit. On October 2, the decision was made to change to a 12 1/4-in.-diameter tri-cone bit in an effort to prevent the diameter of the borehole from expanding in less competent formation material. Upon tripping the 12 1/4-in.-diameter tri-cone bit into the borehole, crews discovered that the borehole had caved in at depth to 1160 ft bgs. The 12 1/4-in.-diameter tri-cone bit was tripped back out of the borehole, and 13 5/8-in.-O.D. drill casing was retracted to 510 ft to prepare for reaming the open hole with a 14 1/2-in. under-reaming bit. An open-hole video log was recorded October 4 after the 13 5/8-in. drill casing was retracted.

The 13 5/8-in.-O.D. drill casing was reinstalled into the borehole using a 14 1/2-in. under-reaming bit and set into competent basalt at 514 ft bgs on October 6. The borehole was then advanced from 1160 ft bgs using a 10 1/2-in.-diameter down-hole hammer bit in advance of 9 5/8-in.-O.D. drill casing, reaching 1345 ft bgs on October 9. The 9 5/8-in.-O.D. drill casing was hung on casing jacks to a depth of 1330 ft bgs on October 10, 2000.

The borehole was advanced open hole from this point using a 10 1/2-in.-diameter down-hole hammer bit to a total depth (TD) of 1489 ft bgs on October 11. (For a diagram of the completed well, see Figure 4.2-1.)

The borehole was visually recorded using the LANL video camera on October 4, 2000. The borehole was drilled to a total depth of 1258 ft bgs (although it sloughed back in to 1160 ft bgs) with 13 3/8-ft steel casing set at 510 ft. The video was run to a depth of 729 ft.

The camera was again run on October 5. The 13 3/8-in. steel casing was retracted to 190 ft bgs, and the camera was run to 250 ft bgs where the hole was too ragged to continue.

On October 12, the borehole was cased to a depth of 1330 ft with 9 5/8-in. casing. A video log was run to 1350 ft, but beyond that point, the water was too murky to continue. A gamma log was run to 1475 ft bgs.

The camera was again run down the hole on October 15. The 9 5/8-in. casing was still landed at 1330 ft bgs, and the camera was run to 1480 ft bgs.

The LANL caliper tool was utilized on October 19 to measure the inside of the well casing. A video log was also taken of the interior of the well.

The LANL gamma tool was utilized on October 25 and 27 inside the well casing to check the precision of the placement of annular backfill material.

The video camera was also run on October 27 to view the screens.

The video camera was run on November 7 and 13 to check on whether screens were cleaning up during development.

On November 20, the gamma tool and video log were run for the last time to view screens and check for backfill placement.

4.0 WELL DESIGN AND CONSTRUCTION

The following sections describe how Laboratory and subcontractor geologists and geophysicists designed the well.

4.1 Well Design

Geophysical logs, video logs, and borehole cuttings were reviewed to plan screen placements for well construction. The number and placement of screens were designed for the following purposes:

- to sample the top of the regional zone of saturation (screens #1 and #2) where two screened intervals were necessary since two distinct static water levels were observed;
- to sample within the upper Puye Formation fanglomerate (screen #3);
- to sample within the older basalt (screen #4); and
- to sample within the lower fanglomerate tentatively assigned to the Puye Formation (screen #5).

Based on both on-site observations during drilling and geophysical logs, we concluded that no perched water was present during the drilling of R-22, therefore all well screens were located in the regional zone of saturation. The planned and actual screen locations are given in Table 4.1-1.

Table 4.1-1
Summary of Well Screen Information for R-22

Screen #	Planned Depth (ft)	Actual Depth (ft)	Geologic/Hydrologic Setting
1	875.4–917.3	872.3–914.2	Top of regional zone of saturation in CdR[a] basalt
2	950.0–991.8	947.0–988.9	Potential top of regional zone of saturation in CdR[a] basalt
3	1274.3–1281.0	1272.2–1278.9	Upper fanglomerate of the Puye Formation
4	1380.2–1386.9	1378.2–1384.9	Older basalt
5	1449.1–1454.1	1447.3–1452.3	Lower fanglomerate (tentatively assigned to the Puye Formation)

[a] CdR = Cerros del Rio.

4.2 Well Construction

From October 17 through October 19, 2000, stainless steel well casing and five stainless steel, pipe-based screens were installed to a TD of 1472.9 ft bgs. Casing centralizers were installed above and below each section of screen and every 100 ft along the blank casing. The annular space was backfilled with alternating intervals of bentonite pellets and sand pack. For stability, cement seals were emplaced at 1335- to 1345-ft bgs, 1132- to 1142-ft bgs, and 0- to 75-ft bgs.

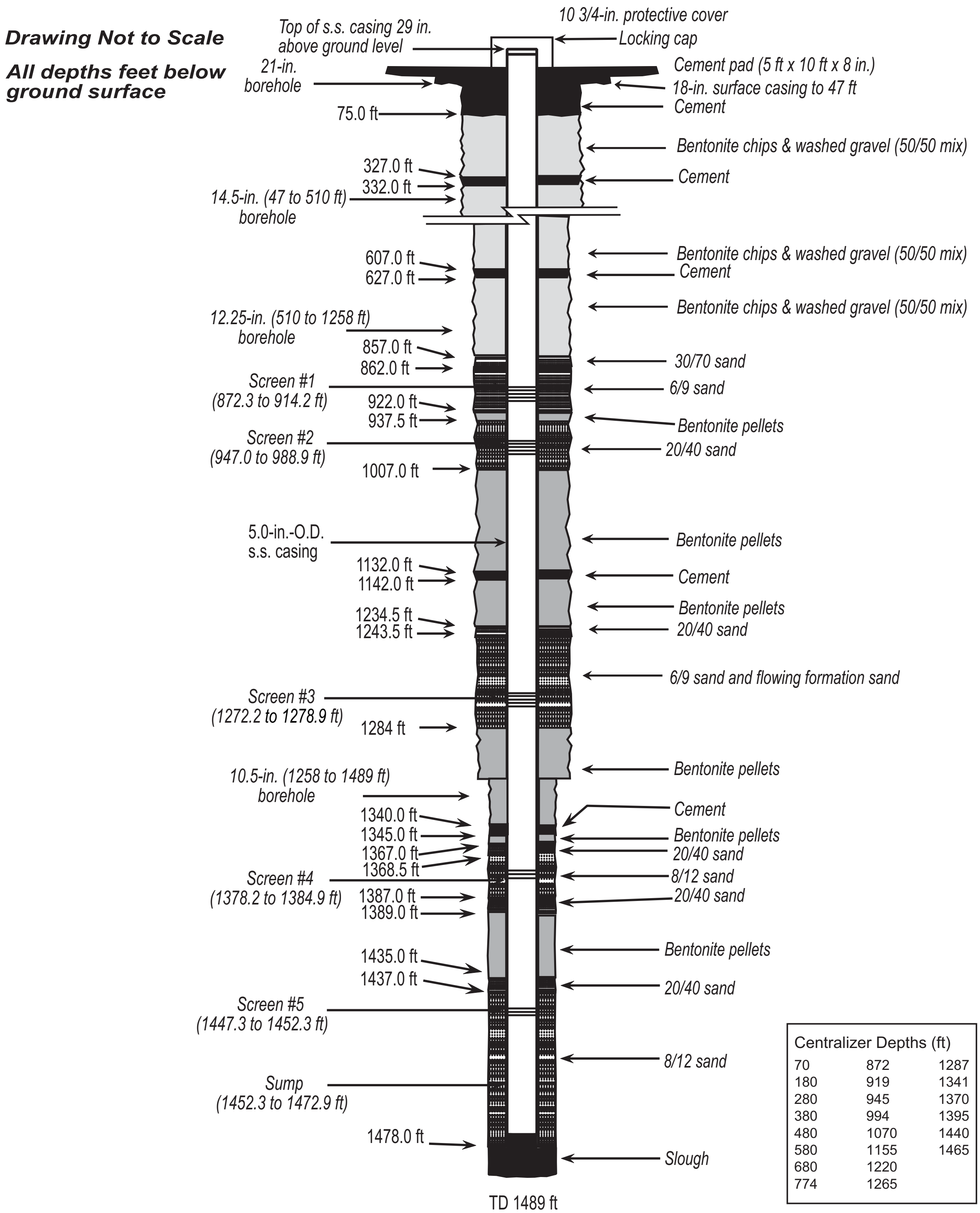
The blank well casing and the pipe-based screens were constructed of 304 stainless steel fabricated to American Society for Testing of Materials (ASTM 1994) A554 standards. External couplings were also type 304 stainless steel. The couplings used were a mix of ASTM standard A312 and A511, both of which exceed the tensile strength of the threaded casing ends. The combination of coupling standards was necessary for the vendor to provide the casing materials in a timely manner and does not compromise the integrity of the well.

The pipe-based screens used throughout the well were constructed of the same diameter tubular as the blank casing risers (4.5-in.-I.D./5.0-in.-O.D. stainless steel). These screens were constructed by drilling 0.375-in.-diameter holes in 10-ft sections of well casing and welding a wire-wrap (0.010-in. gap) over the perforated interval. The final O.D. of the screened intervals was 5.56-in.

The stainless steel well components were cleaned using a hot water cleaner and scrub brushes on-site. The bottom of the borehole was measured at 1478 ft bgs with the tremie line before well casing was installed. The bottom of the well sump was 1472.9 ft bgs. Stainless steel centralizers were installed above and below each screen, and, in several locations, above the zone of regional saturation (Figure 4.2-1). All backfill materials were emplaced through a tremie pipe.

4.2.1 Steel Installation

Well construction consisted of installing stainless steel and carbon steel well tubing as preparation for the multiport Westbay™ sampling apparatus specified in the well design. Dynatec installed the well tubing from October 17, 2000, through October 19, 2000, in four drilling shifts (Table 3.0-1). Stainless steel centralizers were attached to the well tubing below and above each screened interval and spaced evenly at no greater than 50-ft intervals in blank-tubing sections between screens. Figure 4.2-1 is a graphic illustration of the final well tubing configuration and depths bgs.



Centralizer Depths (ft)

70	872	1287
180	919	1341
280	945	1370
380	994	1395
480	1070	1440
580	1155	1465
680	1220	
774	1265	

Note: The screen intervals list the footages of the pipe perforations, not the tops and bottoms of screen joints.

Figure 4.2-1. As-built well configuration diagram, well R-22

4.2.2 Annular Fill Placement

Insertion of annular fill consisted of using a 2 3/16-in. outside diameter, 1 13/16-in. inside diameter steel tremie pipe to deliver annular materials to the specified design depths (Section 4.2). Dynatec installed the annular fill material from October 20, 2000, through November 3, 2000, in 28 drilling shifts (Table 3.0-1). Sands were emplaced at screen intervals and in locations necessary to alleviate backfill slough; they were tremied using municipal water as a fluid slurry. Bentonites were emplaced between screened intervals to seal the annular space and prevent cross communication of groundwater between screens; they were delivered using EZ-MUD® (polyacrylamide-polyacrylate copolymer) mixed with municipal water as a fluid slurry. Portland cement (mixed at a ratio of 5 gal. of water for each 94-lb bag of cement) was used to provide foundations for the annular fill and well-head protection of the annular space in the borehole. (See Figure 4.2-1.) During the insertion of annular fill, several truckloads of municipal water (at approximately 3000 gal. per truckload) were transported to the R-22 site.

Table 4.2-1 is a summary list of the annular fill materials installed. The final configuration of the annular materials is also illustrated in Figure 4.2-1.

Table 4.2-1
Annular Fill Materials, Characterization Well R-22

Material	Amount	Unit
20/40 sand[a]	245	50-lb bags
30/70 sand[b]	27	50-lb bags
6/9 sand[c]	161	50-lb bags
8/12 sand[c]	83	50-lb bags
Yard-Art® gravel[d]	833	50-lb bags
Holeplug® bentonite chips[e]	1000	50-lb bags
Pelplug® bentonite pellets[f]	238	5-gal. buckets
Portland® cement[g]	190	94-lb bags

[a] 20/40 sand is medium-grained and used to pack screened intervals.
[b] 30/70 sand is fine-grained and used to separate screen packs from bentonite.
[c] 6/9 and 8/12 sands are coarse and used to plug formation fractures and matrix pores.
[d] Yard-Art® is an angular ¼-in. gravel used to improve backfilling in washed out or cavernous intervals.
[e] Holeplug® bentonite is 3/8-in. angular and unrefined bentonite chips.
[f] Pelplug® bentonite is 1/4-in. by 3/8-in. refined elliptical pellets.
[g] Portland® cement was mixed with municipal water at a ratio of 5 gal. water for each bag of cement.

5.0 WELL DEVELOPMENT

R-22 was developed by scrubbing, bailing, bailer-surging, and zone-specific pumping. Initial development consisted of scrubbing the inside of the casing and screens with a brush installed on drill pipe. After scrubbing was completed, muddy fluid and settled solids were bailed from the well. The initial high turbidity, pH, and conductivity readings (Figure 5.0-1) were likely due to cement-tainted fluids that apparently entered through screen #3 during backfilling. The 31-ft long x 3-in.-I.D. bailer had a capacity of approximately 11 gal. Bailing was performed initially from November 4 to 11, 2000, and finally from November 12 to 14, 2000. A total of 2095 gal. of water was bailed initially, and a total of 2020 gal. was bailed between November 12 and 14.

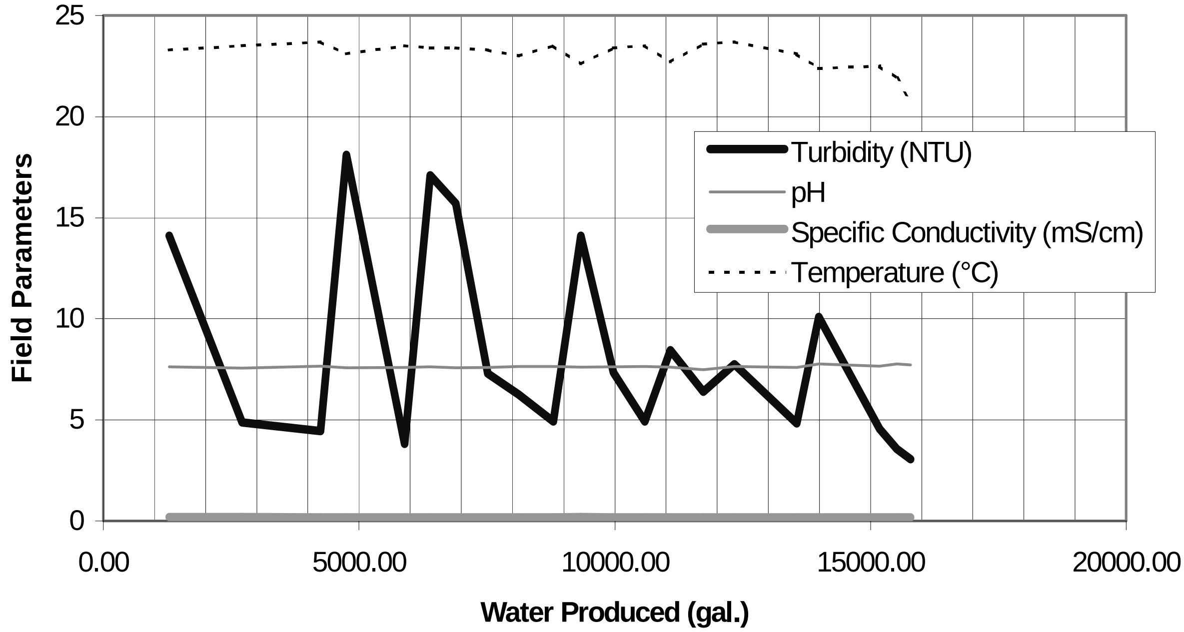


Figure 5.0-1. Results of final development by pumping for screen #4

Development by zone-specific pumping consisted of using a 7.5-hp submersible pump to clean out the sump and to conduct targeted development across from screen #3. A 10-hp submersible pump was then tripped in with an inflatable packer below. Screens #3, #4, and #5 were then pump developed. Screens #1 and #2 did not produce sufficient water for pump development. Pumped water was metered and monitored for turbidity. Each of the zones was pumped at a rate of about 15 gal./min through three on-off cycles or until turbidity of the produced water consistently measured less than 2 NTU (Figure 5.0-1). A total of 34,762 gal. of water was pumped from the well (Table 5.0-1).

Table 5.0-1
Summary of Final (Pumping) Phase of Well Development at R-22

Screen[b]	Elapsed Time (min)[c]	Water produced (gal.)	Range of Field Parameters[a]			
			pH	Temperature (°C)	Specific Conductance (µS/cm)	Turbidity (NTU)
Sump	725	8086	8.7–7.2	16.4–22.8	240–160	42.0–4.3
3	761	4046	8.0–8.0	21.7–20.7	190–170	21.0–3.7
3[d]	705	3319	7.5–7.6	20.6–23.0	160–180	40.5–4.2
4	1303	15,785	7.6–7.7	23.2–20.7	190–170	14.1–3.0
5	473	3526	7.9–7.8	22.6–23.2	170–160	5.6–2.7

[a] Parameters presented as value at beginning followed by value at end of pumping.
[b] Screen #1 was above water table; pumping at screen #2 yielded no water.
[c] Time does not include intervals when pump was turned off.
[d] Screen #3 with packer below screen #3. (Packers not employed for other screens.)

6.0 SURFACE COMPLETION AND SITE RESTORATION

The surface completion for well R-22 involved pouring a 6-in.-thick reinforced concrete pad, 5 ft by 10 ft, around the well casing to ensure long-term structural integrity of the well. The concrete pad also will support a small, lockable steel housing for well instrumentation. The concrete pad was installed in January 2001. A brass survey pin was installed in the concrete pad. In addition, four removable steel bumper posts were installed at the corners of the concrete pad to protect the wellhead from vehicles.

The R-22 site area was recontoured to match the surrounding topography. Before recontouring work began, the cuttings pits were excavated, the plastic linings removed, and the pits refilled. In addition, the R-22 site was cleared of the slash piles created by tree removal during construction of the drill pad.

The hay bales and straw wattles that were part of the R-22 site best-management-practices installations remained in place as needed during and after the postoperational reclamation process. Once the site had been physically reworked, the area underwent reseeding with a LANL-provided blend of native grasses mixed with straw mulch to facilitate reintroduction of ground cover.

During all drilling activities, the archaeological sites proximal to the pad remained undisturbed.

7.0 HYDROLOGIC TESTING

Straddle-packer/slug-injection tests were performed on four of the five screened intervals at R-22 (screens #2, #3, #4, and #5). Screen #1 was not tested because it straddles the water table. (Analytical methods specify that the screen be below water table.)

The test consisted of isolating each suitable screened interval with a pair of inflatable packers and injecting municipal water at a constant rate for a short period of time. The rate of injection was monitored by means of a flow meter and a watch with a second hand. The flow meter was installed between the water-supply tank and the Bean pump on the drill rig. Pretest water-level depth was determined using an electric probe. Water-level depth during testing was monitored with a transducer and datalogger. Complete details of test design and execution are given in a report being prepared separately.

8.0 WESTBAY™ INSTRUMENTATION

Following well development, the Westbay™ MP55 system for groundwater monitoring was installed in the steel-cased well. Model 2523 MOSDAX® System sampler probe equipment provides the ability to collect groundwater samples from each of the five isolated screens in the completed well.

A multiport (MP) casing installation log, which specifies the location of each Westbay™ component in the borehole, was prepared in the field by Westbay™ in consultation with the Laboratory based on the R-22 well-completion diagram. Available geophysical logs and an as-built video log taken inside the steel well casing were also reviewed before measurement ports and packers were sited within the well screen intervals. The final version of the MP casing installation log was approved in the field on December 5, 2000, by the Laboratory prior to installation of the Westbay™ components. The MP casing installation log as approved was used as the installation guide in the field.

An MP measurement-port coupling and associated magnetic location collar were included in each primary monitoring zone to provide the capability to measure fluid pressures and collect fluid samples. A pumping port coupling was also included in screened zones to provide purging, sampling and hydraulic conductivity testing capabilities. Additional measurement-port couplings were included below the pumping ports for monitoring hydraulic tests.

Measurement port couplings were included in quality assurance (QA) zones to provide QA testing capabilities. All QA measurement ports were positioned below each of the MP55 packers to permit routine operation of the squeeze relief venting with the MP55 packer inflation equipment during the inflation process.

The MP casing components were set out in sequence according to the MP casing installation log on racks near the borehole. As an aid in confirming the proper sequence of components, each casing length was numbered in order, beginning with the lowermost. The appropriate MP System® coupling was attached to each piece of MP casing. Magnetic location collars were attached 2.5 ft below the measurement ports in each of the primary monitoring zones and 2.5 ft below MP Coupling No. 168 near the top of the well.

The length of each MP casing section was measured with a steel tape to confirm nominal lengths, and the data were entered on the field copy of the MP casing installation log. Each casing component was visually inspected, and serial numbers for each packer, measurement port coupling, and pumping port coupling were recorded on the field copy of the MP casing installation log.

The MP casing components were lowered into the well in sequence. Crews used a Smeal work-over rig provided by the Laboratory. Each casing joint was tested with a minimum internal pressure of 300 pounds per square inch for one minute to confirm hydraulic seals. Deionized water was used for the joint tests. A record of each successful joint test and the placement of each casing component is on the field copy of the MP casing installation log. The suspended weight of the MP casing components was monitored during lowering to confirm that operating limits of the MP System casing components were not exceeded. Lowering of the MP casing to the target position was successfully completed on December 8, 2000.

After the casing was lowered into the borehole, the water level inside the MP casing was left at a depth of 1227 ft bgs to confirm hydraulic integrity of the casing. The open-hole water level was 947.3 ft bgs. With this differential pressure acting on the MP casing string, the water level inside the MP casing was stable over a measurement period of 30 min, and the measured pressures were stable. The test indicated that the MP casing was watertight.

After the components were lowered into the well and the hydraulic integrity of the MP casing had been confirmed, the MP casing string was positioned as shown in Appendix D. The MP packers were inflated on December 9 and 10, 2000, using deionized water. The packers were inflated in sequence beginning with the lowermost. All of the packers were inflated successfully, and QA tests showed that all of the packer valves were closed and sealed.

Westbay's™ standard procedure for destressing the MP casing was used after all of the packers had been inflated. The top MP55 casing was cut and trimmed to suit the final configuration of the wellhead assembly, and the MP top completion was installed. The final load at the top of the MP casing was 400 lb. A sketch of the as-built top of the MP casing and final positions of the MP well components are shown in Appendix D. A summary of depth information for key MP well components is shown on Table 8.0-1.

After packer inflation was completed, fluid pressures were measured at each measurement port. The fluid pressure profile measurements were taken on December 11, 2000. At that time, the in-situ formation pressures may not have recovered from the preinstallation and installation activities. Longer-term monitoring may be required to establish representative fluid pressures.

Table 8.0-1
Depths of Key Items Installed During R-22 MP55 Completion

Zone No.	Screen Interval[a] (ft)	Sand Pack Interval[a] (ft)	MP Casing No. (from MP Log)	Packer No.	Packer Serial No. (0612)	Nominal Packer Position[b] (ft)	Magnetic Collar Depth (ft)	Measurement Port Depth[b] (ft)	Pumping Port Depth[b] (ft)	Port Name	Comments
QA-1			124				447.0	444.5		QA-2	
			123	1	205	454.7					
QA-2			83				None	842.7		QA-1	
			82	2	215	852.9					
SQA1			81				None	857.4		SQA1	
			80	3	217	862.8					
Zone 1	872.3 to 914.2	860 to 920	78				879.6	877.1		MP1V	For vadose zone sampling
			75				889.6	907.1		MP1A	
			74						912.4	PP1	
			73					918.1		MP1B	
			72	4	212	928.4					
SQA2			71					932.8		SQA2	
			70	5	214	938.2					
Zone 2	947 to 988.9	937 to 1001	67				965.3	962.8		MP2A	
			66						967.7	PP2	
			65					973.4		MP2B	
			63	6	203	993.5					
LQA2			62					998.0		LQA2	
			36	7	188	1254.2					
SQA2			35					1258.7		SQA3	
			34	8	220	1264.1					

Table 8.0-1 (continued)

Zone No.	Screen Interval[a] (ft)	Sand Pack Interval[a] (ft)	MP Casing No. (from MP Log)	Packer No.	Packer Serial No. (0612)	Nominal Packer Position[b] (ft)	Magnetic Collar Depth (ft)	Measurement Port Depth[b] (ft)	Pumping Port Depth[b] (ft)	Port Name	Comments
Zone 3	1272.2 to 1278.9	1260.3 to 1290.9	32					1273.5		MP3A	
			31				1276.0		1278.9	PP3	
			30					1284.5		MP3B	
			29	9	216	1288.2					
LQA3			28					1292.7		LQA3	
			20	10	221	1358.8					
SQA4			19					1363.3		SQA4	
			18	11	207	1368.6					
Zone 4	1376.2 to 1384.9	1366.3 to 1394.9	16				1380.5	1378.0		MP4A	
			15						1383.4	PP4	
			14					1389.1		MP4B	
			13	12	210	1392.8					
LQA4			12					1397.3		LQA4	
			7	13	208	1428.9					
SQA5			6					1433.4		SQA5	
			5	14	206	1438.8					
Zone 5	1447.3 to 1452.3	1435.3 to 1478.0	3				1450.7	1448.2		MP5A	
			2						1453.6	PP5	
			1					1459.2		MP5B	

Note: QA is quality assurance; SQA is short quality assurance; LQA is long quality assurance; MP is measurement port; and PP is pumping port.

[a] Backfill materials are not AS BUILT.

[b] All depths of MP System casing components are the depth to the top of the respective coupling.

A plot of the piezometric levels in all zones, including QA zones, based on the December 11 pressure measurements, was examined to confirm proper operation of the measurement ports and as a check on the presence of annulus seals between adjacent monitoring zones. All the measurement ports operated normally. Each of the packers below the open-hole water level was supporting a differential hydraulic pressure, indicating the presence of packer seals.

9.0 GEODETIC SURVEY OF COMPLETED WELL

Regional groundwater characterization well R-22 was geographically surveyed using the Global Positioning System (GPS) on January 9, 2001. Transmitted signals from eight satellites were available through most of the survey. A Trimble 4000 SSE dual-frequency base receiver was set up and initialized over control monument A5402 in TA-54 for conduct of the real-time kinematic survey. Coordinate values for the control were from the 1992/1993 GPS Survey establishing the LANL control network. The coordinate values are published in the LANL Survey Monument Network Manual, and the monuments are certified to have been placed in conformance with standards and specifications for Order 2-1 surveys or greater. The datum for the control network is North America Datum of 1983 (NAD-83). Results are summarized in Table 9.0-1. X and Y coordinates are given as New Mexico state plane coordinates.

Table 9.0-1
Geodetic Data for Well R-22

Description	East	North	Elevation
Brass cap in R-22 pad	1645324.4	1757111.1	6650.5
Top of plate on casing	1645326.9	1757111.8	6652.2
Top of collar on casing	1645326.9	1757111.9	6652.7

PART II: ANALYSES AND INTERPRETATIONS

10.0 GEOLOGY

The placement of drill hole R-22, in the east-central portion of the Laboratory, is shown in Figure 10.0-1. This location, at the eastern edge of waste disposal areas within TA-54, is important for defining the stratigraphy at depth where little prior information was available beyond the reach of relatively shallow boreholes within TA-54. Figure 10.0-1 also shows a line-of-section between drill holes R-19, PM-2, R-22, and an outcrop in White Rock Canyon described by Dethier (1997, 49843). This line-of-section (Figure 10.0-2) is discussed in Section 16 at the end of this report. A low cinder mound, remnant of a tholeiitic volcanic vent in the Cerros del Rio volcanic field, is ~1.5 km southeast of R-22 and just west of White Rock.

Geologic units encountered in R-22 consist of, in descending order: ash flows of the Tshirege Member of the Bandelier Tuff; ash-flow tuffs of the Otowi Member of the Bandelier Tuff including the basal Guaje Pumice Bed; lavas, cinder units, interflow units, and subflow deposits of the Cerros del Rio volcanic field; an upper sequence of fanglomerate deposits of the Puye Formation; an older basalt; and a lower sequence of fanglomerate deposits of the Puye Formation. Depths and elevations of the contacts between these units are shown in Figures 10.0-3 and 10.0-4, with a comparison to the predicted stratigraphy based on the 3-D Geologic Model available at the time drilling began in Figure 10.0-3. The most notable difference between the predicted and as-drilled stratigraphy is the greater thickness of the Cerros del Rio volcanic sequence, which places the regional water table and the upper ~300 ft of regional saturation within the Cerros del Rio rather than in Puye fanglomerates. The exceptional thickness and variety of Cerros del Rio lavas at R-22 provides an opportunity for placing the different lavas of the Cerros del Rio into stratigraphic context. Much of the detailed description in this section focuses on the Cerros del Rio lavas because of this opportunity, which is important for volcanic stratigraphic correlation within the LANL 3-D Geologic Model. Other notable discoveries at R-22 include the absence of Puye Formation axial river gravels (Totavi) and the absence of Santa Fe Group sediments within the depth drilled. These absences are important new information for the LANL 3-D Geologic Model, and the nature of the sediments that occur in place of these gravels and Santa Fe Group sediments is part of the analysis provided in this report. A summary of unit characteristics is given in the following sections, and a lithologic log is provided in Appendix C.

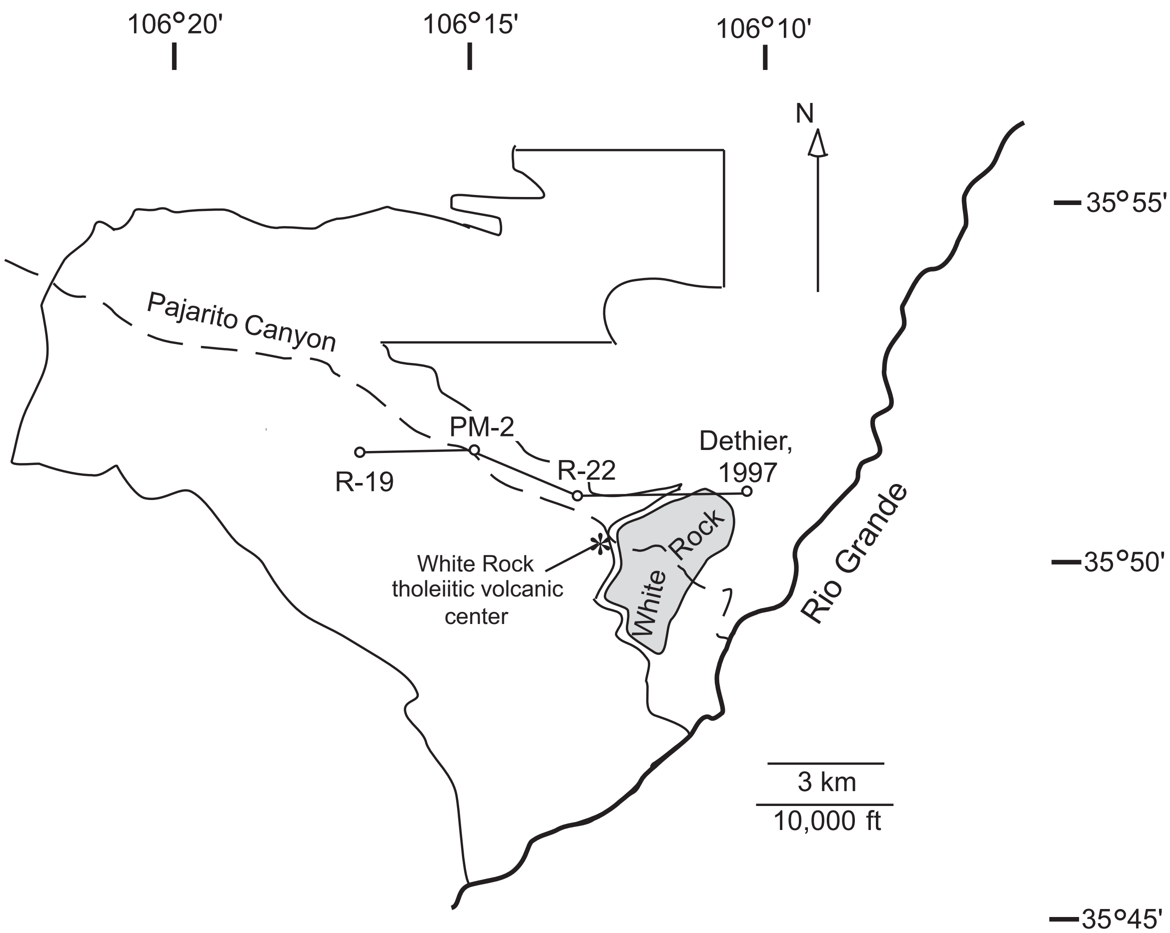


Figure 10.0-1. Map showing the location of drill hole R-22 relative to the Laboratory boundary, the town of White Rock, and the tholeiitic volcanic center west of White Rock. The line-of-section from R-19 to PM-2, through R-22 to the rim of White Rock Canyon (Dethier 1997, 49843) corresponds to Figure 10.0-2.

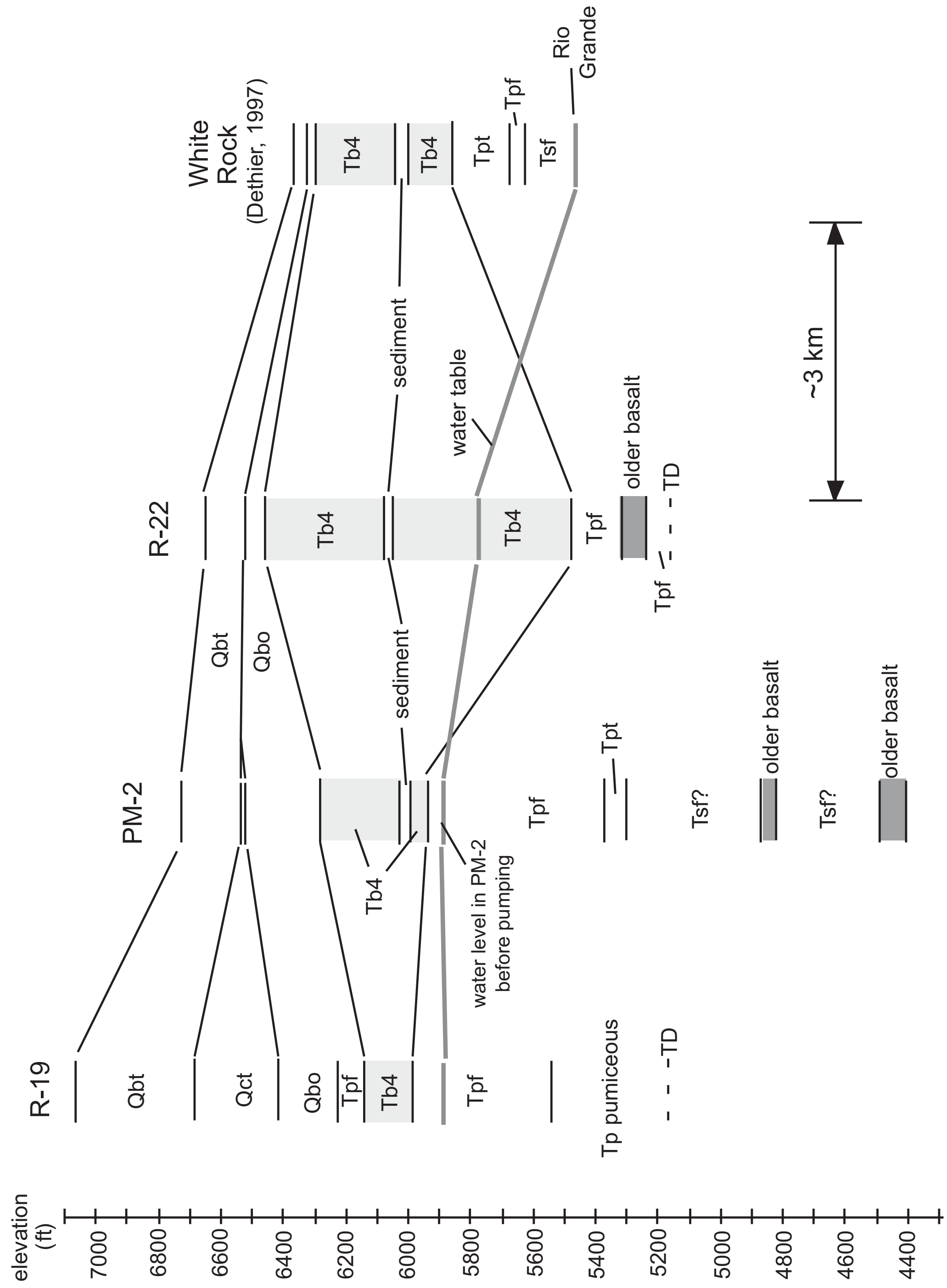


Figure 10.0-2. Cross-section through R-22 corresponding to the line-of-section shown in Figure 10.0-1. Symbols used represent the Tshirege Member of the Bandelier Tuff (Qbt), Cerro Toledo deposits (Qct), the Otowi Member of the Bandelier Tuff (Qbo), Puye Formation fanglomerates (Tpf), a pumiceous unit included within the Puye (Tp pumiceous), axial river gravels of the Puye Formation ("Totavi," Tpt), Cerros del Rio volcanic rocks (Tb4), and Santa Fe Group sediments (Tsf).

Figure 10.0-2. Cross-section through R-22 corresponding to the line-of-section shown in Figure 10.0-1. Symbols used represent the Tshirege Member of the Bandelier Tuff (Qbt), Cerro Toledo deposits (Qct), the Otowi Member of the Bandelier Tuff (Qbo), Puye Formation fanglomerates (Tpf), a pumiceous unit included within the Puye (Tp pumiceous), axial river gravels of the Puye Formation ("Totavi," Tpt), Cerros del Rio volcanic rocks (Tb4), and Santa Fe Group sediments (Tsf).

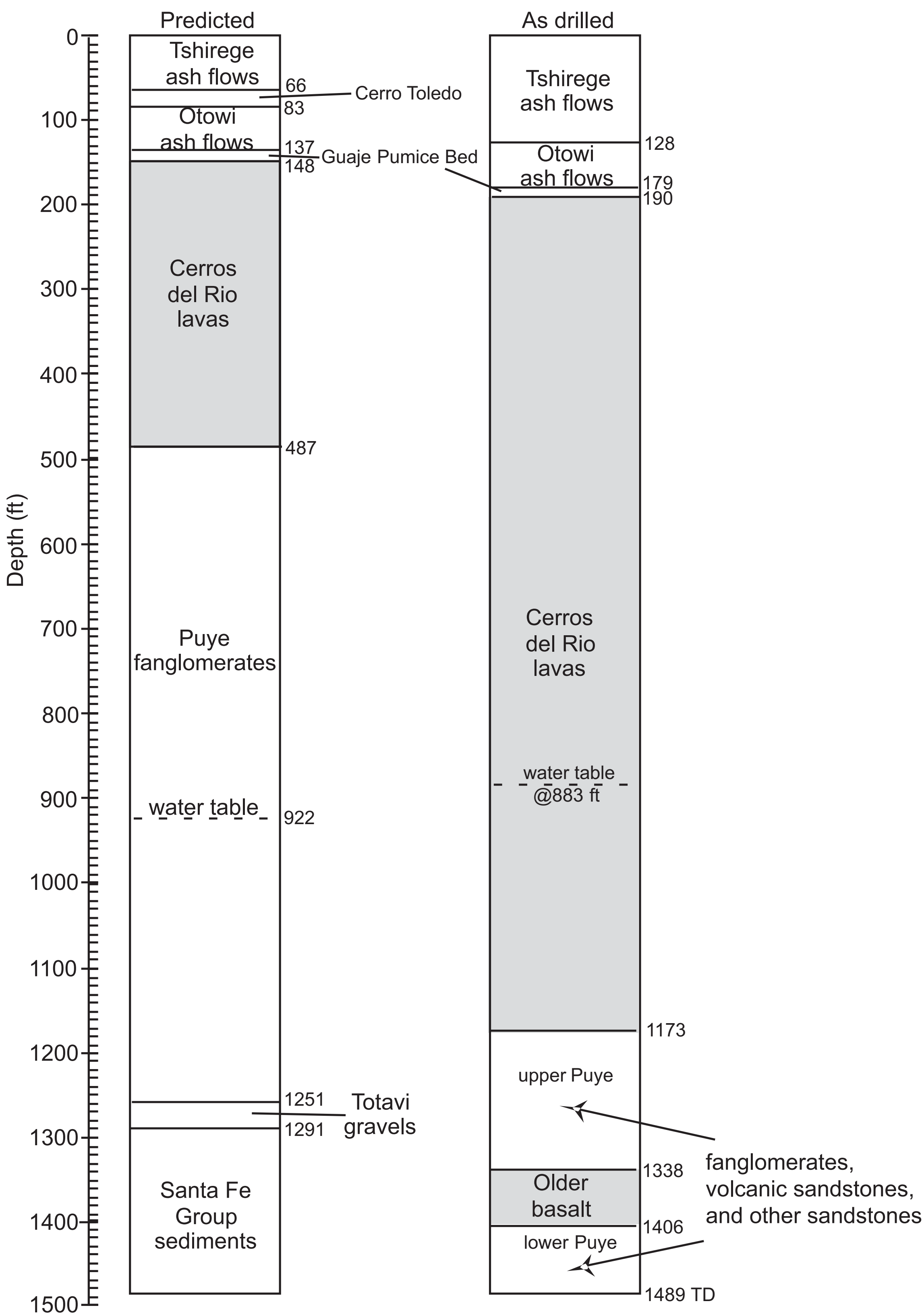


Figure 10.0-3. The stratigraphy predicted prior to drilling of R-22 compared with the as-drilled stratigraphy

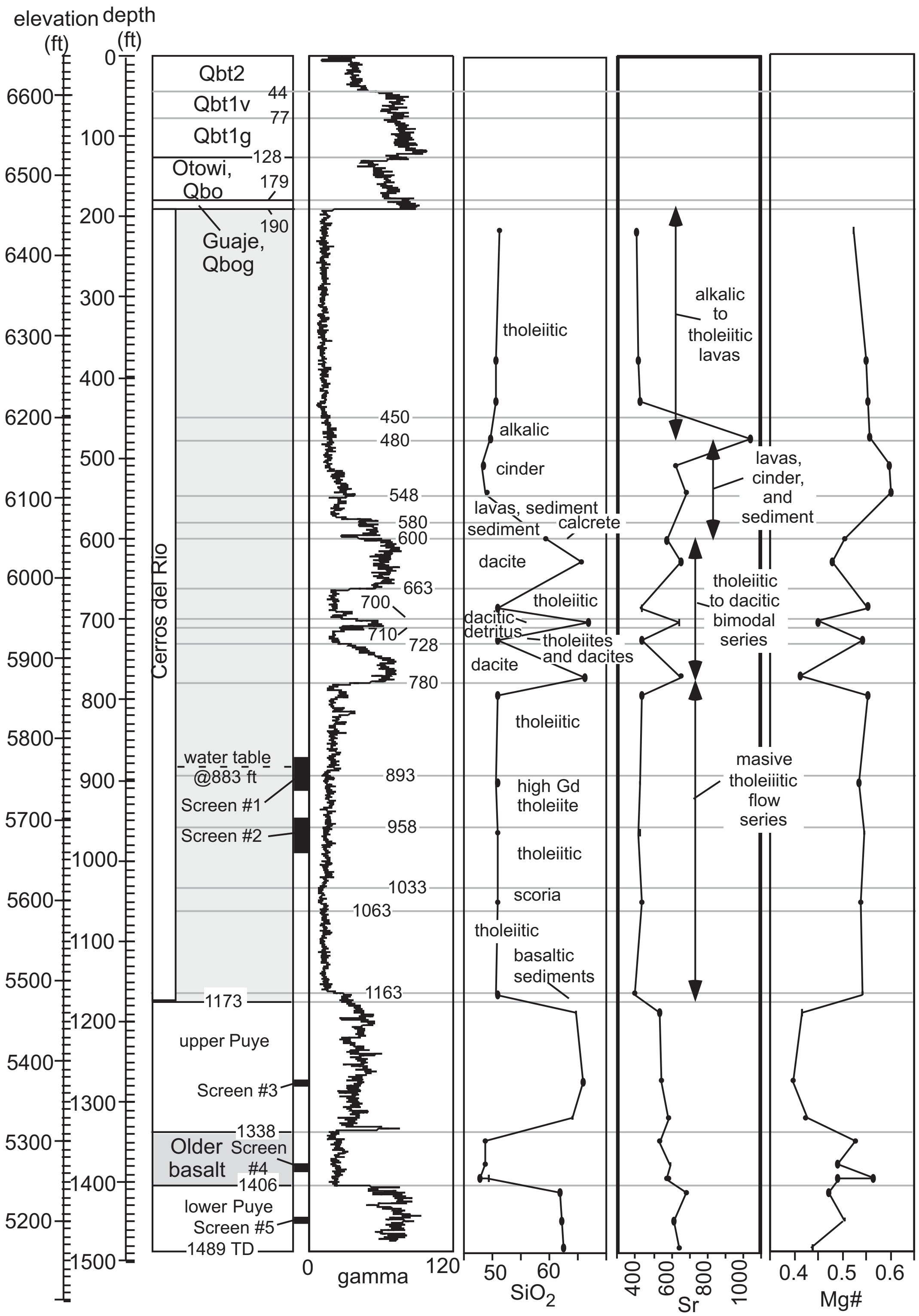


Figure 10.0-4. Detailed stratigraphy at R-22, comparing the natural gamma signal obtained at R-22 and the silica content, strontium content, and Mg# [cation ratio of Mg/(Mg+Fe)] of analyzed samples. Points in the SiO_2, Sr, and Mg# columns show the locations of analyzed samples in Tables 10.3-1, 10.3-2, and 10.3-3. Arrows demarcate the four major subdivisions of the Cerros del Rio.

Descriptions of geologic units are based on examination of cuttings, geophysical logs (including video logs), and laboratory examination of borehole materials. No core was collected at R-22, but cuttings were collected by reverse circulation, minimizing admixture of materials from upper portions of the borehole.

Cuttings samples were used to gather petrographic, mineralogic, and geochemical data from units beneath the Bandelier Tuff. Petrographic data were obtained both by binocular microscope examination of cuttings at the site and by petrographic microscope using thin sections prepared from representative cuttings samples (Appendix E). Mineralogic data were obtained by quantitative x-ray diffraction (QXRD). Geochemical data were collected from cuttings samples by x-ray fluorescence (XRF). All of these data provide a basis for stratigraphic correlation. The mineralogic and geochemical data provide information about soluble glass content and composition, clay occurrences, and mineralogic controls of oxidation potential [Eh] and pH.

Figures that illustrate the as-drilled stratigraphy (Figures 10.0-4 and 10.0-5) also show the locations of screened intervals (Westbay™ MP55 system) in the completed well at R-22 in relation to the intervals sampled for lithologic analysis. The geologic samples at screen locations are particularly important for relating geochemistry, petrology, mineralogy, and sedimentology to the interpretation of water samples collected from those screened intervals. The preliminary data for evaluating these relations are provided in this report.

10.1 Ash Flows of the Tshirege Member of the Bandelier Tuff (0- to 128-Ft Depth)

The Tshirege ash flows at the Laboratory have been subdivided into four cooling units on the basis of surface mapping (Broxton and Reneau 1995, 49726). Two of these cooling units, Qbt 2 and Qbt 1v/1g, are present at Mesita del Buey where R-22 was drilled. The drilling conducted at R-22 was very effective at powdering the ash matrix and pumices of the Tshirege, leaving concentrations of intermediate-composition lava lithic inclusions and providing only limited stratigraphic information concerning the host tuff. However, outcrop exposures and extensive shallow coring at TA-54 show that Tshirege flow units Qbt 2, Qbt 1v, and Qbt 1g are all present at this site. Because of the poor preservation of ash and pumice in cuttings, identification of the Qbt 2/Qbt 1v contact was not possible from the samples produced at R-22; however, outcrop data and drill cores nearby at TA-54 indicate that this contact is at ~40 ft depth. The identification of the devitrified to vitric transition at Qbt 1v/Qbt 1g is more readily determined from cuttings and is at ~77-ft depth in R-22.

Before R-22 was drilled, it was expected that thin occurrences of the Tsankawi Pumice Bed and of Cerro Toledo sediments would be encountered. The cuttings produced no evidence of either, although thicknesses of a few inches of one or both may be present.

10.2 Ash Flows and Guaje Pumice Bed of the Otowi Member of the Bandelier Tuff (128- to 179-Ft Depth and 179- to 190-Ft Depth)

Otowi Member ash-flow tuffs are 51 ft thick at R-22. These vitric ash-flow tuffs have a natural gamma signal that characteristically increases with depth (Figure 10.0-4). A similar increase with depth occurs in the Tshirege Member, and the drop in natural gamma signal near 128-ft depth marks the transition between these two members of the Bandelier Tuff. The Guaje Pumice Bed is placed at the abrupt rise in the natural gamma signal at 179-ft depth. (See Figure 10.0-4). Data from the Elemental Capture Survey (ECS) geophysical log (Appendix G) indicate a rise in hydrogen content within the Guaje Pumice Bed, suggesting increased moisture content (although perched water was not detected during drilling). This increase in water content is not associated with evidence of clay alteration, indicating the possibility of increased water-bearing pore space within the porous pumice beds.

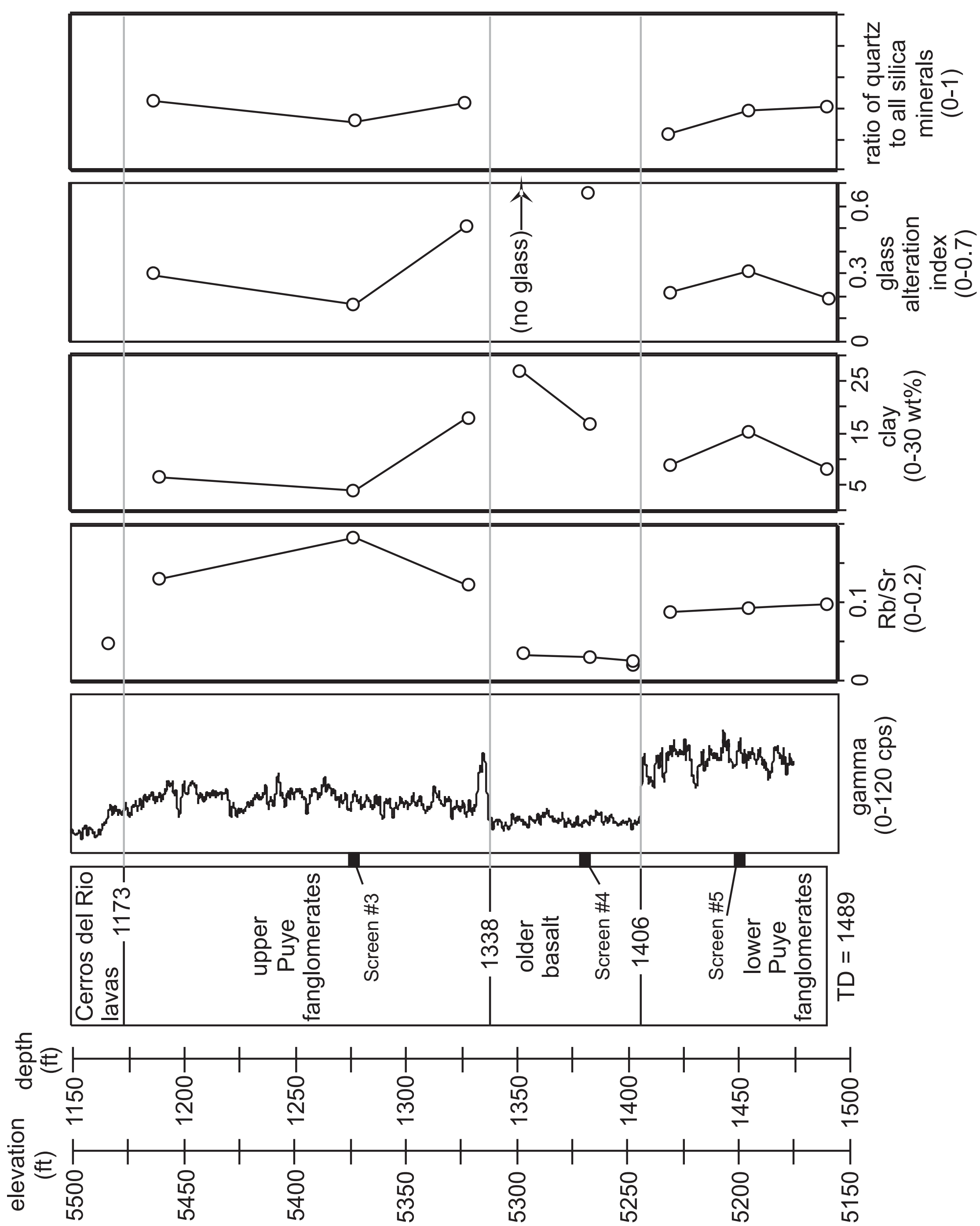


Figure 10.0-5. Lower stratigraphic sequence at R-22 encompassing the upper Puye fanglomerates, the older basalt, and the lower Puye fanglomerates. The natural gamma signal is plotted along with Rb/Sr ratios (from Tables 10.3-1 and 10.3-2), clay content, glass alteration index [clay/(glass + clay)] from Table 10.3-3], and ratio of quartz to all silica minerals [quartz/(quartz + tridymite + cristobalite)] from Table 10.3-3].

Figure 10.0-5. Lower stratigraphic sequence at R-22 encompassing the upper Puye fanglomerates, the older basalt, and the lower Puye fanglomerates. The natural gamma signal is plotted along with Rb/Sr ratios (from Tables 10.3-1 and 10.3-2), clay content, glass alteration index [clay/(glass + clay) from Table 10.4-1], and ratio of quartz to all silica minerals [quartz/(quartz + tridymite + cristobalite) from Table 10.4-1].

10.3 Cerros del Rio Surface Soil, Lavas, Cinder Units, Interflow Units, and Subflow Deposits of the Cerros del Rio Volcanic Field (190- to 1173-Ft Depth)

Surface soil with basaltic detritus, lavas, cinder accumulations, interflow rubble or scoria zones, and subflow deposits of the Cerros del Rio volcanic field were encountered in the interval from 190 to 1173-ft depth. Because of borehole stability problems encountered in the upper part of the Cerros del Rio lavas, casing was carried from the upper Cerros del Rio to TD. Casing was briefly retracted to 510 ft depth on October 4, 2000, to allow video analysis of the open borehole. However, large fissures and loose boulders were encountered at 729 ft in the upper part of a dacitic lava series. The camera was not run below this depth because of the risk of tool loss or damage. Thus the available open borehole video for R-22 is limited to the interval from 510 to 729 ft. Cuttings and borehole geophysics (natural gamma, density, and geochemical logs) were used to define the four major subdivisions of the Cerros del Rio that are marked by arrows in column 4 of Figure 10.0-4.

10.3.1 Cerros del Rio Alkalic to Tholeiitic Lavas (190- to 480-Ft Depth)

The upper 290 ft of Cerros del Rio lavas at R-22 is a sequence that passes from alkalic to tholeiitic composition from bottom to top (Figure 10.0-4). Detritus, surface soil, and some pedogenic carbonate were returned with the cuttings from 190- to 207-ft depth. The lavas below this surface material are represented by cuttings samples at 217- to 222-ft depth, 377- to 382-ft depth, 427- to 432-ft depth, and 472- to 477-ft depth (columns 1 through 4 of Table 10.3-1). The upper three samples are tholeiitic and relatively constant in composition and petrographic character. These tholeiites are olivine-porphyritic with ~3% to 4% olivine phenocrysts and with subophitic clinopyroxene (clinopyroxenes that partially encase lath-shaped feldspar crystals). The lowest sample is alkalic, with a much higher strontium (Sr) content (1045 vs. 405 to 424 ppm Sr; Table 10.3-1) and more abundant olivine phenocrysts (~10%). The olivine-rich alkalic basalt at 472- to 477-ft depth includes both lava and basaltic cinder, indicating proximity to a vent. The systematic decrease in magnesium number (Mg#) [cation ratio of Mg/(Mg + Fe)] from bottom to top in this sequence (Figure 10.0-4) suggests that fractional crystallization of olivine may relate the lavas of this series.

The occurrence of this upper alkalic to tholeiitic eruption series is common to the Cerros del Rio lava stratigraphy in many drill holes of the eastern Laboratory (R-9, R-12, R-15, and R-31). Correlation of these lavas between drill holes may extend this thick upper lava series across broad areas of the Laboratory, but although such correlation is possible, more data are needed to test this possibility. There is a notable compositional similarity between the upper tholeiites at R-22 and an analyzed sample from the volcanic vent near White Rock, ~1.5 km to the southeast. (See Figure 10.0-1 and compare WoldeGabriel et al. [1997, 54427], their sample 93-13, with columns 1–3 of Table 10.3-1 in this report.)

10.3.2 Cerros del Rio Basaltic Lavas and Cinder (480- to 580-Ft Depth) above a Sediment and Soil Horizon (580- to 600-Ft Depth)

Samples from 480- to 600-ft depth at R-22 are complex, including a zone with basaltic cinder from 480- to 548-ft depth and interbedded basaltic and dacitic lavas and possible sediments from 548- to 580-ft depth. The samples from 580- to 600-ft depth include sediments and soils with little evidence of lava flows. A basal calcrete from this sequence was also sampled for analysis.

Table 10.3-1
XRF Analyses of Lavas from R-22

	1	2	3	4	5	6	7	8	9	10
Sample Number[a]	R-22 217-222 (tholeiitic lava)	R-22 377-382 (tholeiitic lava)	R-22 427-432 (tholeiitic lava)	R-22 472-477 (alkalic lava)	R-22 507-512 (basaltic cinder)	R-22 543-548 (basalt)	R-22 628-633 (dacitic lava)	R-22 683-688 (tholeiitic cinder)	R-22 703-708 (dacitic lava)	R-22 723-728 (tholeiitic lava)
Unit[b]	CdR	CdR	CdR	CdR	CdR	CdR	CdR	CdR	CdR	CdR
XRF Data (major elements)										
SiO_2 %	51.10	50.51	50.50	49.61	48.01	48.68	65.26	50.73	66.57	50.69
TiO_2 %	1.42	1.51	1.45	1.68	1.79	1.70	0.52	1.48	0.51	1.49
Al_2O_3 %	16.11	15.72	15.55	16.63	15.08	15.36	15.06	15.55	15.33	15.80
FeO %[c]	6.84	7.49	8.13	5.42	5.53	5.84	1.83	7.87	1.09	7.34
Fe_2O_3 %[c]	3.63	3.14	2.43	4.30	5.29	4.71	2.05	2.65	2.75	3.29
MnO %	0.16	0.17	0.16	0.16	0.17	0.16	0.08	0.17	0.07	0.17
MgO %	6.19	7.03	7.21	6.57	8.60	8.51	1.90	7.13	1.64	6.85
CaO %	8.86	8.77	8.76	8.17	8.87	8.52	3.68	8.73	3.72	8.85
Na_2O %	3.26	3.20	3.28	4.08	2.74	3.05	3.70	3.03	4.20	3.19
K_2O %	0.91	0.99	0.98	1.61	1.33	1.36	3.38	1.11	2.90	1.01
P_2O_5 %	0.27	0.29	0.30	0.70	0.51	0.50	0.26	0.30	0.26	0.31
LOI %[d]	-0.18	-0.43	-0.48	-0.30	0.34	0.01	1.37	-0.04	0.30	-0.23
Total %	98.74	98.82	98.76	98.92	97.91	98.40	97.72	98.75	99.04	98.99
XRF Data (trace elements)										
V ppm	170	178	178	178	203	192	54	187	55	200
Cr ppm	144	229	248	110	269	237	23	239	23	229
Ni ppm	82	101	120	91	175	184	19	101	<12	108
Zn ppm	89	90	94	90	84	90	48	87	55	98
Rb ppm	20	18	19	26	29	25	52	21	48	21
Sr ppm	405	418	424	1045	624	685	656	425	647	430
Y ppm	30	31	31	29	31	24	9	24	23	36
Zr ppm	138	150	150	239	181	186	195	149	176	152
Nb ppm	14	16	19	36	26	28	33	28	23	21
Ba ppm	377	366	328	906	628	648	1368	434	1354	410

Note: Values reported in percent or parts per million by weight. Analytical errors (2σ) are SiO_2, 0.7; TiO_2, 0.01, Al_2O_3, 0.2; Fe_2O_3, 0.06; MnO, 0.01; MgO, 0.08; CaO, 0.1; Na_2O, 0.1; K_2O, 0.05; P_2O_5, 0.01; V, 10; Cr, 8; NI, 10; Zn, 12; Rb, 5; Sr, 25; Y, 6; Zr, 30; Nb, 7; and Ba, 50.

Table 10.3-1 (continued)

	11	12	13	14	15	16	17	18	19	20
Sample Number[a]	**R-22 768-773 (dacitic lava)**	**R-22 793-798 (tholeiitic lava)**	**R-22 903-908 (tholeiitic lava)**	**R-22 963-968 (tholeiitic lava)**	**R-22 1053-1058 (tholeiitic lava)**	**R-22 1163-1168 (tholeiitic lava)**	**R-22 1347-1352 (tholeiitic lava)**	**R-22 1377-1382 (tholeiitic lava)**	**R-22 1397-1402- (tholeiitic lava)**	**R-22 1397-1402- (tholeiitic lava)**
Unit[b]	**CdR**	**CdR**	**CdR**	**CdR**	**CdR**	**CdR**	**older**	**older**	**older**	**older**
XRF Data (major elements)										
SiO_2 %	66.00	50.75	50.56	50.64	50.78	50.51	48.38	48.58	47.52	48.91
TiO_2 %	0.52	1.49	1.48	1.49	1.51	1.48	1.75	1.75	1.57	1.98
Al_2O_3 %	15.37	15.59	15.70	15.56	15.89	15.59	15.78	16.31	15.80	15.92
FeO %[c]	0.95	6.45	6.74	7.81	6.52	5.44	2.41	2.55	3.28	7.77
Fe_2O_3 %[c]	2.93	3.88	3.88	2.81	3.93	5.17	7.85	7.89	6.46	3.05
MnO %	0.08	0.16	0.16	0.17	0.16	0.15	0.14	0.14	0.13	0.17
MgO %	1.41	6.90	6.59	6.90	6.61	6.68	5.94	5.20	6.67	5.72
CaO %	3.78	8.93	8.85	8.87	8.94	8.82	10.19	10.20	11.01	9.90
Na_2O %	4.22	3.18	3.05	3.17	3.01	3.14	3.08	3.26	2.94	3.31
K_2O %	2.93	1.07	1.18	1.10	1.12	0.99	0.92	0.90	0.77	0.97
P_2O_5 %	0.27	0.32	0.31	0.31	0.31	0.31	0.40	0.37	0.33	0.44
[d]LOI %	0.37	-0.02	0.06	-0.05	0.14	0.94	2.18	1.46	2.73	0.17
Total %	98.46	98.72	98.52	98.82	98.77	98.27	96.85	97.15	96.49	98.15
XRF Data (trace elements)										
V ppm	57	186	173	184	183	188	220	218	215	249
Cr ppm	23	250	221	244	232	230	220	221	239	192
Ni ppm	17	131	99	105	102	106	98	84	84	66
Zn ppm	49	88	90	94	79	99	84	77	72	94
Rb ppm	47	22	21	18	30	18	19	18	15	12
Sr ppm	653	438	422	420	435	395	536	591	577	568
Y ppm	16	23	39	25	37	33	39	29	25	41
Zr ppm	185	153	147	150	150	146	158	164	137	169
Nb ppm	29	15	13	20	16	15	22	18	12	16
Ba ppm	1398	526	400	366	365	398	491	468	306	470

[a] Number ranges indicate depth ranges of cuttings in feet; notes in parentheses indicate separated subsample types within that depth range.

[b] Unit designations are “CdR” for Cerros del Rio volcanic rocks and “older” for the older basalt.

[c] Ferrous/ferric ratio determined by digestion/titration.

[d] LOI = loss on ignition; negative numbers indicate oxidation of ferrous iron during ignition.

The zone of basaltic cinder at 480 to 548 ft is represented by a sample from 507- to 512-ft depth that includes vitric basaltic cinder that is moderately alkalic (624 ppm Sr; column 5 on Table 10.3-1). Crystals in the cinder include very large olivine phenocrysts (up to 2 mm in size) and small plagioclase laths. This high olivine content corresponds with the highest Mg# among Cerros del Rio samples at R-22 (Figure 10.0-4). Traces of Precambrian quartzite are present and may represent either xenoliths or minor river gravels.

The varied basaltic and dacitic lavas and possible sediments below the basaltic cinder are represented by a sample from 543 to 548 ft. The thin section of representative clasts from this cuttings run includes a porphyritic olivine basalt (10% olivine) (represented in column 6 of Table 10.3-1) and a variety of dacitic samples, including both holocrystalline and vitric lithologies. The dacitic lithologies include both clinopyroxene-orthopyroxene porphyritic and clinopyroxene-amphibole porphyritic samples.

The 20-ft sediment/soil horizon at 580- to 600-ft depth may include more than one paleosol; however, the calcrete at the base of this sequence (selected cuttings from 598- to 603-ft depth) is a prominent indicator of soil development and was therefore selected for analysis. Data for this soil sample include chemical analysis (column 1, Table 10.3-2), mineralogic analysis by x-ray diffraction (XRD) (row 1, Table 10.3-3), and petrographic analysis (Appendix E). The chemical and mineralogic features of the calcrete include high CaO and high loss on ignition (LOI) that match its high calcite content of 61 wt%. There is a modest clay content (8%) in the calcrete and no evidence of pedogenic silica (opal) in either XRD or petrographic analysis. Petrographically, the calcrete forms thick (>2 mm) laminated rinds with ooidal structures, coating basalt clasts. The thickness, structure, and calcite abundance indicate a very mature soil formed in a dry environment. Calcrete can have hydrogeologic significance as a barrier to downward flow in the vadose zone; in geophysical logging the ECS hydrogen measurement (Appendix G) is elevated from ~430 to 600 ft, suggesting that the moisture content may be enhanced above the buried calcrete horizon at ~600 ft.

10.3.3 Cerros del Rio Tholeiitic/Dacitic Bimodal Volcanic Series (600- to 780-Ft Depth)

A sequence of 180 ft of lavas and cinder from 600- to 780-ft depth includes both tholeiitic and dacitic volcanic lithologies. The deposits within this sequence include a 63-ft thick dacite lava series (600- to 663-ft depth), a 37-ft thick tholeiitic cinder sequence (663 to 700 ft), a very thin series (10 ft) of dacitic detritus (700 to 710 ft), a 18-ft zone that includes both tholeiitic and dacitic lithologies (710 to 728 ft), possibly detrital, and a 50-ft thick set of dacite lavas (728 to 780 ft).

All of the dacite samples in this 180-ft thick sequence are clinopyroxene-orthopyroxene-plagioclase porphyritic dacite with sieved and resorbed plagioclase phenocrysts. The matrix textures in the dacites show evidence of moderate to strong flow orientation (pilotaxitic texture) of plagioclase laths. Chemical analyses of representative dacites from throughout this sequence are essentially identical to each other (columns 7, 9, and 11 of Table 10.3-1). The upper part of the lower dacite series, from 728 down to at least 740 ft, was found, on video examination, to contain large fissures in excess of the borehole diameter (>13 in). Borehole instability in this dacitic lava precluded running the camera any deeper.

The tholeiitic component of this sequence is represented by two samples that are also very similar to each other in composition (columns 8 and 10, Table 10.3-1) and in petrographic character (Appendix E). Both are olivine-porphyritic basalts with subophitic clinopyroxene, although the sample from the tholeiitic cinder deposit at 683 to 688 ft has a greater abundance of glass relative to crystalline constituents.

The occurrence of tholeiitic cinder indicates a source vent that is not far away from the R-22 drill site. Nearby volcanic sources are indicated for this bimodal tholeiitic/dacitic sequence at 600- to 780-ft depth, for the overlying tephra-bearing sequence at 480- to 580-ft depth, and for the uppermost alkalic to tholeiitic sequence with affinity to the volcanic vent ~1.5 km distant. No such sources are evident for the thick tholeiitic sequence that lies beneath.

Table 10.3-2
XRF Analyses of Soil and Puye Fanglomerate Samples from R-22

	1	2	3	4	5	6	7
Sample Number[a]	**R22-598-603-soil**	**R22-1188-1191**	**R22-1273-1278**	**R22-1323-1328**	**R22-1412-1417**	**R22-1447-1452**	**R22-1482-1487**
XRF Data (major elements)							
SiO_2 %	19.50	64.32	65.64	63.70	61.58	62.00	62.29
TiO_2 %	0.17	0.73	0.63	0.79	0.92	0.83	0.89
Al_2O_3 %	3.87	15.11	15.36	15.77	16.13	16.18	15.74
[b]Fe_2O_3 %	1.14	5.18	4.03	5.12	5.16	4.46	4.74
MnO %	0.02	0.07	0.06	0.08	0.09	0.09	0.08
MgO %	1.85	1.85	1.34	1.92	2.31	2.27	1.85
CaO %	39.03	3.74	2.93	3.66	4.12	3.91	3.80
Na_2O %	0.59	3.56	3.87	3.37	3.68	3.17	3.41
K_2O %	0.68	3.27	3.96	2.96	2.97	2.75	3.10
P_2O_5 %	0.18	0.27	0.24	0.25	0.35	0.31	0.36
LOI %[b]	32.07	1.01	1.05	1.85	1.74	2.86	2.62
Total %	67.01	98.11	98.05	97.63	97.32	95.98	96.24
XRF Data (trace elements)							
V ppm	<10	79	69	87	86	76	80
Cr ppm	<8	50	<8	23	23	31	14
Ni ppm	<11	23	<12	19	19	25	20
Zn ppm	<12	61	52	59	62	67	64
Rb ppm	21	71	99	72	61	60	64
Sr ppm	426	538	539	589	689	618	643
Y ppm	11	29	22	26	23	35	37
Zr ppm	122	199	252	265	301	269	267
Nb ppm	9	16	22	27	37	24	35
Ba ppm	383	1061	1117	1064	1280	1033	1150

Note: Values reported in percent or parts per million by weight. Analytical errors (2σ) are SiO_2, 0.7; TiO_2, 0.01, Al_2O_3, 0.2; Fe_2O_3, 0.06; MnO, 0.01; MgO, 0.08; CaO, 0.1; Na_2O, 0.1; K_2O, 0.05; P_2O_5, 0.01; V, 10; Cr, 8; NI, 10; Zn, 12; Rb, 5; Sr, 25; Y, 6; Zr, 30; Nb, 7; and Ba, 50.

[a] Number ranges indicate depth ranges of cuttings in feet.

[b] LOI = loss on ignition; negative numbers indicate oxidation of ferrous iron during ignition.

Table 10.3-3
XRD Analyses of Samples from R-22

Sample[a]	Smectite	Tridymite	Cristobalite	Quartz	Alkali Feldspar	Plagioclase	Glass	Pyroxene	Hematite	Biotite	Hornblende	Apatite	Calcite	Dolomite	Total
Calcrete (S) and basalt (B) within Cerros del Rio															
(1) R-22 598-603 S	8.0	—	—	4.0	2.3	12.2	11.0	—	—	—	—	—	61.0	—	98.5
(2) R-22 598-603 B	—	—	—	—	0.5	34.1	55.2	4.5	—	—	0.1	0.9[b]	3.8	0.8	99.9
Upper Puye															
(3) R-22 1181-1191	6.4	1.0	7.1	6.4	16.6	42.5	15.3	—	1.2	2.2	0.1	—	—	—	98.7
(4) R-22 1273-1278	4.0	2.0	7.2	4.1	20.1	40.4	20.7	—	1.1	2.2	0.1	—	—	—	101.9
(5) R-22 1323-1328	17.7	2.0	4.6	5.0	13.6	39.1	16.8	—	0.8	1.3	0.2	—	—	—	101.2
Older Basalt, Altered															
(6) R-22 1347-1352	26.7	—	—	0.0	1.3	54.3	—	17.6	0.6	—	—	—	—	—	100.5
(7) R-22 1377-1382	16.6	—	—	0.1	2.3	51.9	8.5	19.4	0.6	—	0.2	—	—	—	99.6
Lower Puye															
(8) R-22 1412-1417	8.7	0.5	3.6	1.2	5.0	43.3	31.7	6.5	0.7	0.2	0.2	—	—	—	101.5
(9) R-22 1447-1452	15.3	0.5	3.2	2.3	4.6	36.4	33.7	3.9	0.4	0.1	—	—	—	—	100.4
(10)R-22 1482-1487	8.1	0.5	3.9	3.0	7.7	37.2	34.9	5.5	0.5	0.4	—	—	—	—	101.6

Note: Values reported are in weight percent. Analytical errors (2σ) are ~5% of the amount reported for abundances >10% and ~10% of the amount reported for abundances <10%. Dashes indicate that the phase was not detected. (Detection limits are ~0.1%.)

[a] Number ranges indicate depth ranges of cuttings in feet.

[b] Preliminary value.

10.3.4 Cerros del Rio Massive Tholeiitic Flow Series (780- to 1163-Ft Depth) and Flow-Base Sediments (1163- to 1173-Ft Depth)

The lowest Cerros del Rio flow sequence at R-22 is an exceptionally thick (383 ft) and homogenous mass of tholeiitic basalt. This sequence is represented by five chemical analyses that are so similar they fall within the range expected of replicate analyses from a single flow (columns 12 through 16, Table 10.3-1). This homogeneity can be seen in Figure 10.0-4, where the gamma, SiO_2, Sr, and Mg# curves through this sequence are all essentially flat. However, the extreme thickness of this sequence, petrographic differences between samples, presence of a thick scoria zone at 1033- to 1063-ft depth, and occurrence of mixed volcanic gravels at 1133- to 1138-ft depth all indicate that this sequence is made up of multiple flows from several eruption cycles. Moreover, ECS borehole logging suggests a subset of these lavas between 893 and 958-ft depth with relatively high gadolinium (Gd) and hence higher lanthanide-element content than the other tholeiites of the sequence. Nevertheless, occurrence of such a thick and homogeneous sequence is unusual in the Cerros del Rio volcanic system and contrasts greatly with the intercalated tholeiitic, alkalic, and dacitic variants at higher levels within the Cerros del Rio at R-22.

Petrographically, these chemically homogeneous tholeiites are all olivine-porphyritic with subophitic clinopyroxene, although glass abundances and phenocryst sizes vary (Appendix E). The most distinctive of the samples is from the basaltic sediments at the bottom of the sequence (sample at 1163- to 1168-ft depth), where essentially all olivine has been replaced by yellow to yellow-brown clay, and vesicles are filled with coarse calcite. This type of alteration indicates that the first tholeiite flows of the sequence were emplaced over wet sediments. The higher Fe_2O_3/FeO ratio in this sample, compared with the unaltered tholeiites, is evidence of oxidation along with the clay alteration, although other chemical parameters (with the possible exception of slight Sr loss) are essentially unchanged. (Compare column 16 with columns 12 through 15 in Table 10.3-1.) Extensive clay alteration in the flow-base sediments at 1163- to 1173-ft depth also suggests palagonitic alteration of basaltic scoria.

10.4 Upper Puye Fanglomerates (1173- to 1338-Ft Depth)

The Puye Formation occurs as two fanglomerate sequences at R-22—an upper sequence from 1173- to 1338-ft depth, and a lower sequence from 1406-ft depth to TD at 1489 ft. Between these two sequences is a heavily clay-altered basalt that is at present considered to be of Miocene age, based on similarities to another basalt at the bottom of drill hole R-9 that has been radiometrically dated at ~8.5-8.6 mega annum (Ma). (See Section 10.5, below.) If the basalt between the two Puye sequences at R-22 is indeed that old, then the duration of fanglomerate deposition from volcanic highlands to the west must extend to times that predate Tschicoma volcanism and may represent deposits of volcanic detritus from the Keres volcanic cycle.

Figure 10.0-5 illustrates several geochemical and mineralogic parameters for the two Puye fanglomerate sequences and the intercalated clay-altered basalt. The rubidium (Rb) and Sr data used in generating this figure are listed in Table 10.3-2, and the mineralogic data are listed in Table 10.3-3. The natural gamma signal is from the Laboratory natural gamma tool, operated through 9 5/8 in. casing. Figure 10.0-5 compares Rb/Sr ratio, clay content, a glass alteration index (ratio of glass to glass plus clay), and the ratio of quartz to all silica minerals [quartz/(quartz + tridymite + cristobalite)]. The last two parameters are, respectively, measures of the extent of alteration and of the relative abundance of quartz (abundant in plutonic and metamorphic source rocks) to all silica minerals including those that occur in the matrices of intermediate-composition volcanic rocks (tridymite and cristobalite).

The upper Puye fanglomerates at R-22 have Rb/Sr ratios of 0.12–0.18, typical of Tschicoma dacitic sources in upper-level Puye fanglomerates (0.1–0.2; Broxton et al. 2001, 66603). This range of Rb/Sr ratios is higher than that in basalts (0.02–0.05) and in dacitic lavas of the Cerros del Rio (0.07–0.08), but lower than that of deeper pumiceous Puye deposits found to the west at R-19 (>0.5; Broxton et al. 2001, 66603). The Rb/Sr values of 0.12–0.18 thus make the upper fanglomerates at R-22 fairly typical in comparison with other Puye fanglomerate compositions. The low ratio of quartz among silica polymorphs in the fanglomerates (Figure 10.0-5) is also typical. Petrographic data for the 2-4 mm clast fraction of the two upper samples (1188- to 1191-ft depth and 1273- to 1278-ft depth) indicate that this fanglomerate series contains clasts from a mixture of intermediate-composition volcanic lithologies, including lavas and pumices, with either anhydrous or hydrous mafic phenocrysts or both (Appendix E). Fragments of basaltic or metamorphic lithologies including quartzite occur but are rare (averaging ~4%). The lower sample, at 1323-to-1328-ft depth, consists predominantly of clay-matrix clasts of immature volcanic sandstone, but these sandstones are derived from volcanic source rocks similar to the lithologies represented as coarser rock fragments. The higher clay content of the sample at 1323- to 1328-ft depth is reflected in its higher glass alteration index (Figure 10.0-5).

10.5 Clay-Altered Older Basalt (1338- to 1406-Ft Depth)

The basalt at 1338- to 1406-ft depth, between the two sequences of Puye fanglomerates, is a heavily clay-altered tholeiite. The chemical composition of this tholeiite is represented by four analyses listed as columns 17 through 20 in Table 10.3-1. All of the samples listed there are selected from relatively unaltered cuttings, but some clay alteration occurs in each. The mineralogic analyses of two samples are listed in Table 10.3-3 (rows 6 and 7). These samples include a split selected from 1347- to 1352-ft depth for evident alteration and a more representative sample split from 1377- to 1382-ft depth. Both of these samples show evidence of clay alteration without associated silica, calcite, or zeolite formation.

Comparison between this older (*i.e.*, pre-Cerros del Rio) basalt at R-22 and that at drill hole R-9 to the north (Broxton et al. 2001, 66599) indicates significant chemical similarity. The chemical similarity between relatively unaltered R-9 and R-22 older basalts suggests a correlation between the two, but further analyses including radiometric dating will be needed to evaluate this possibility. Two argon-40/argon-39 ($^{40}Ar/^{39}Ar$) ages have been obtained for the older basalt at R-9, yielding a reasonably well bracketed age of 8.5 to 8.6 Ma.

The sample of R-22 older basalt at 1377- to 1382-ft depth represents the lithology at Westbay™ screen #4 (1378.2- to 1384.9-ft depth). The significant clay alteration in this sample (~17% smectite) may be a factor in reducing flow at this screen, even if the basalt at this depth is fractured.

10.6 Lower Fanglomerates, Tentatively Assigned to the Puye Formation (1406- to TD at 1489-Ft Depth)

A lower sequence of fanglomerates extends from 1406-ft depth to the TD of R-22 at 1489 ft. These fanglomerates bear some similarities to the upper Puye fanglomerates, but there are several significant differences between the two. The lower fanglomerate sequence is less siliceous and has lower Rb/Sr ratios than the upper fanglomerates (0.09–0.10 vs. 0.12–0.18; Table 10.3-2 and Figure 10.0-5). This decrease in SiO_2 and Rb/Sr with depth corresponds with a rise in Mg# (Figure 10.0-4) and differs from the Puye trend in drill holes to the north (R-9, R-12) and to the west (R-19, CdV-R-15-3) where the chemical evolution of the Puye over time is from more siliceous to less siliceous volcanic sources. Petrographically, the lower Puye fanglomerates at R-22 are dominated by a dacitic lithology characterized by a single type of anhydrous mafic phenocryst (clinopyroxene). Other intermediate-composition volcanic clasts are present, but this clinopyroxene-porphyritic lithology predominates in all samples of these lower fanglomerates. The lower fanglomerates also contain two-pyroxene, clinopyroxene-amphibole, and clinopyroxene-biotite lithologies plus partially-altered pumices of intermediate composition. The deepest sample (1482- to 1487-ft depth) has a small amount (~5%) of siliceous metamorphic lithologies including biotite-muscovite metagranite, a kyanite quartzite, and strained quartz of metamorphic origin (Appendix E). The shallower samples in the lower fanglomerates lack these lithologies from distant sources and contain fragments of immature volcanic sandstones, probably derived from local sources, that are rare in the deepest sample.

If the older basalt at R-22 is correlative with that at R-9 (see section 10.5 above), then the lower Puye fanglomerates at R-22 are older than ~8.5–8.6 Ma. If this is the case, the lower R-22 fanglomerates are likely to have been derived from pre-Tschicoma volcanic sources. The closest volcanic rocks of appropriate age and composition are those of the Keres series of silicic, intermediate, and basaltic lithologies that occupied much of the area west and southwest of the Laboratory site. Volcanism in this field was active between ~13 and 7 Ma. Given the potentially considerable age of the lower fanglomerates at R-22, it is reasonable to question whether these deposits should be included within the Puye Formation or should be assigned to another stratigraphic system similar in genesis to the Puye but related in time to Keres volcanism, such as the Cochiti Formation. This question should be addressed if radiometric dating of the older basalt at R-22 confirms a Miocene age.

11.0 BOREHOLE GEOPHYSICS

Schlumberger Wireline & Testing did the borehole geophysical logging measurements for Characterization Well R-22 in October 2000 after the borehole reached TD. Schlumberger's complete report is included in this document as Appendix F (on the enclosed compact disk).

The primary purpose of Schlumberger's work was to acquire measurements that would help characterize the borehole and near-borehole hydrogeologic environment. Such information is used to design the well, to improve understanding of subsurface site conditions, and to assist in decision-making.

The logs were acquired in a 9.269-in. diameter steel casing. The primary geophysical logging services performed and the tools used to perform them were as follows:

- Compensated Neutron Tool, model G, used in the vadose zone to measure volumetric water content beyond the casing as a means to evaluate moist/porous zones and to estimate porosity in the saturated zone;
- Hostile Natural Gamma Spectroscopy (HNGS) tool, used to measure overall and spectral natural gamma ray activity, including potassium, thorium, and uranium concentrations as a means to evaluate geology/lithology and the presence of clay vs. sand;
- Elemental Capture Spectroscopy tool, used to measure concentrations of hydrogen, silicon, calcium, sulfur, iron, potassium, titanium, and gadolinium as a means to characterize mineralogy, lithology, and water content of the formation; and
- Litho-Density Tool, used to measure bulk density and photoelectric effect as a means to estimate total porosity and characterize lithology.

In addition, Schlumberger recorded calibrated gross gamma ray readings with every service except HNGS to match the depth of the logging runs.

Schlumberger reported that, overall, most of the geophysical log measurements from Well R-22 provided good quality results.

The company did note that the moisture and bulk density logs appeared to be severely influenced by water between the casing and the borehole wall below the water level. The result was highly elevated water-filled porosity measurements in many intervals below the water level.

Similarly, Schlumberger reported that the bulk density log was highly influenced by air between the casing and borehole wall above the water level. The result was recording of erroneously low bulk density and high air-filled porosity data in many intervals above the water level.

Schlumberger said, however, that the moisture measurements above the water level and the spectral gamma ray and elemental weight percent measurements throughout the well were generally unaffected by these annular voids.

Schlumberger concluded that the log results indicated the following conditions:

- a well water level of 955 ft below surface and a probable regional groundwater level of 886 ft at the time of logging;
- increased vadose zone moisture content in the intervals between 50 ft and 180 ft (an average of 5%) and between 350 ft and 715 ft (10% or greater);
- increased saturated zone porosity (greater than 40%) in the interval from 1405 ft to 1478 ft (log total depth) corresponding to the Lower Puye Formation; and
- clearly defined stratigraphic/lithologic boundaries (shown in the spectral gamma and geochemical logs).

(See Appendix F for a more complete discussion of geophysical logging results.)

12.0 HYDROLOGY

Based on data from nearby wells and the sitewide geologic model, it was predicted that R-22 would encounter two zones of perched saturation in addition to the regional zone of saturation. The perched zones were expected in the Cerros del Rio basalt at a depth of 148 ft and in the Puye Formation at a depth of 487 ft. The regional water table was predicted to lie at a depth of 922 ft in the Puye Formation at this location.

12.1 Saturated Zones

This section discusses the occurrence and movement of water in the saturated zones at R-22.

12.1.1 Groundwater Occurrence

The two possible occurrences of perched water expected in the Cerros del Rio basalt and Puye Formation did not materialize. Rather, the drillers first noted water at a depth of approximately 890 to 900 ft in the Cerros del Rio basalt. After 30 min, water-level depth was measured to be 883.05 ft. This water is believed to be associated with the regional zone of saturation for three reasons: (1) the regional water table was projected to lie at a similar depth (922 ft); (2) no obvious perching horizon was encountered; and (3) the saturation continues to TD.

The most productive saturated material is a 165-ft thick interval of Puye Formation underlying the Cerros del Rio basalt. The least productive is an interval of basalt beneath the gravel. An 83-ft thick interval of volcaniclastic gravel, tentatively assigned as part of the Puye Formation, between the basalt and TD is moderately productive.

12.1.2 Groundwater Movement

Characterizing groundwater movement requires both a direction and a rate. Although data for evaluating horizontal flow direction is not provided by a single well, vertical direction of movement can be determined by analysis of head distribution along the borehole. A general idea of potential flow rate is provided by the hydraulic properties of the saturated materials determined from analysis of data from field testing.

12.1.2.1 Vertical Head Distribution

The direction of vertical gradient, that is, whether water movement is upward or downward, is best determined by examining water-level depths or elevations (heads) measured at different borehole depths. If water-level depth increases or head decreases with borehole depth, then the direction of the vertical gradient is downward. Conversely, if the water-level depth decreases or head increases with borehole depth, the direction of vertical gradient is upward. This gradient direction can be checked by comparison with head distributions obtained in the completed well either (1) during straddle-packer/injection testing or (2) from transducers in the Westbay™ monitoring system.

Attempts to measure water-level depth were made during pauses in drilling by means of an electric probe lowered down the drill rod. As casing was advanced during drilling at R-22, there was a considerable length of cased hole whenever water-level measurements were attempted, and only composite values could be obtained. Although not suitable for determining hydraulic head, such values can indicate the general direction of vertical gradient. Unfortunately, it was difficult to measure water level at R-22 as the probe became fouled by drilling fluid adhering to the inside of the drill rod before reaching standing water. However, heads obtained during testing clearly indicate a downward gradient and thus confirm the location of R-22 in a recharge area. The piezometric profile constructed by Westbay at the time of installation of the MOSDAX® System, a pressure-measurement system, (after testing) also shows declining head with depth or a downward vertical gradient at R-22.

12.1.2.2 Hydraulic Properties

Hydraulic properties may be determined from laboratory tests on core samples or from field tests targeting screened intervals. Although no core samples were taken from the saturated zone, and thus no lab tests were possible, field tests were performed, as described in Section 7.0. Preliminary results of testing are given in Table 12.1-1. Screen #1 was not tested as it straddles the water table. Single tests were conducted on screens #2, #3, and #5. Screen #4 was tested twice to check reproducibility of results. Both tests involved exactly the same test conditions (injection rate and duration). Except for screen #2, the hydraulic conductivity values obtained are all of the same order of magnitude. Complete details of test analysis will be given in a report being prepared separately.

Table 12.1-1
Summary of Straddle-Packer/Injection Testing at R-22[a]

Screen # (unit)[b]	Static Water Level Elevation (ft)	Average Injection Rate (gal./min)	Duration of Injection (min)	Hydraulic Conductivity (ft/d)[c]
1 (Tb)	(Straddles water table; not tested)			
2 (Tb)	5744	9.12	20	0.27
3 (Tp)	5702	12.0	10	2.32
4a (Tsfb)	5690	16.0	3	2.00
4b[d]		16.0	3	2.07
5 (Tp)	5690	17.0	3	1.57

[a] Preliminary; values may change slightly upon further analysis.

[b] Tb = Cerros del Rio basalt; Tp = Puye Formation; Tsfb = Santa Fe Group basalt.

[c] Based on analysis by Bouwer-Rice method (Bouwer and Rice 1976, 64056).

[d] Repeat of test on screen #2.

13.0 GEOCHEMISTRY OF SAMPLED WATERS

Two screening borehole water samples were collected from R-22 and analyzed for a limited suite of constituents. Potential contaminants of concern at R-22 include volatile organic compounds, perchloric acid, tritium, and other radionuclides disposed at TA-54 (Hydrogeologic Workplan, LANL 1998, 59599).

13.1 Methods

Groundwater samples for inorganic, organic, and radionuclide constituents were collected using a stainless-steel bailer at 883 and 1489 ft at R-22. Temperature, turbidity, pH, and specific conductance were not determined on-site due to equipment malfunction. (The portable meter that reads these parameters failed in the field.) Both filtered (major anions) and nonfiltered (volatile organic compounds, high explosive [HE] compounds, semivolatile compounds, radionuclides, and stable isotopes of nitrogen) samples were collected for chemical and radiochemical analyses. Aliquots of the samples were filtered through a 0.45-µm Gelman filter and acidified with analytical-grade HNO_3 to a pH of 2.0 or less for radionuclide analyses. All groundwater samples collected in the field were stored at 4°C until they were analyzed. Alkalinity was determined in the laboratory using standard titration techniques, which may approximate field conditions due to sample degassing.

Groundwater samples were analyzed using techniques specified in EPA SW-846 methodologies including ion chromatography (IC) for bromide, chloride, fluoride, phosphate, and sulfate; gas chromatography-mass spectrometry (GC/MS) for volatile and semivolatile organic compounds. Contract laboratories for this work included Paragon Analytics, Inc. (organic compounds) and General Engineering Laboratories (GEL) (anions).

Radionuclide activity in borehole water was determined by direct counting and electrolytic enrichment for low-level tritium; alpha spectrometry for americium, plutonium, and uranium isotopes; gas proportional counting for strontium-90; and gamma spectrometry for cesium-137 and other gamma-emitting isotopes. Contract laboratories including Paragon Analytics, Inc. (radionuclides) and the University of Miami (low-level tritium) performed this work.

HE compounds and associated degradation products of 2,4,6-trinitrotoluene (TNT) were analyzed by high-pressure liquid chromatography (HPLC) at Paragon Analytics, Inc.

Coastal Science Laboratories, Inc., Austin, Texas, using isotope ratio mass spectrometry (IRMS), analyzed stable isotopes of nitrogen (nitrogen-15 and nitrogen-14).

Laboratory blanks were analyzed in accordance with EPA and Laboratory procedures. The precision limits for major ions and trace elements were generally ±10%.

Because of the presence of EZ-MUD®, QUIK-FOAM®, and other drilling fluids, these borehole water samples are not representative of groundwater, especially in low-yield saturated zones. Consequently, these data are used only for screening purposes to assist drilling decisions. Groundwater samples will be collected and analyzed for major ions, trace metals, stable isotopes, organic compounds, selected radionuclides, and other chemicals during characterization sampling.

13.2 Geochemistry of Regional Aquifer—Cerros del Rio Basalt

The activity of tritium at the regional water table (883 ft) was 109 pCi/L (Table 13.2-1). This screening value suggests that recent recharge to the regional aquifer at R-22 has occurred since the early 1940s. At this activity, it cannot be determined if this tritium represents Laboratory discharge or relatively fast infiltration of worldwide fallout tritium from precipitation.

Table 13.2-1
Hydrochemistry of Borehole R-22, Mesita del Buey

Depth (ft)	883	1489
Geologic Unit	**CR basalt**	**Puye Formation**
Date Sampled	**09/30/00**	**10/11/00**
Tritium (pCi/L)	109.2	3.13
Am-241 (pCi/L)	0.057, U	—
Sr-90 (pCi/L)	-0.5, U	—
Pu-238 (pCi/L)	-0.006, U	—
Pu-239,240 (pCi/L)	0.027, U	—
U-234 (pCi/L)	1.48	—
U-235 (pCi/L)	0.126	—
U-238 (pCi/L)	1.41	—
HCO_3^- (mg /L)	120	—
Br (mg/L)	<0.016, U	—
Cl (mg/L)	21.0	—
F (mg/L)	1.19	—
C_2O_4 (oxalate) (mg/L)	1.05	—
ClO_4^- (perchlorate) (µg/L)	<1.04 U	
PO_4 (as P) (mg/L)	<0.2, UJ	—
SO_4 (mg/L)	19.9	—
Acetone (mg/L)	0.820	—
2-A-4,6-DNT (mg/L)	0.0017, J	—
2-Butanone (mg/L)	0.010, J	—
2,4-Dinitrotoluene (mg/L)	0.0031	—
Methylene chloride (mg/L)	0.0046, J	—
Nitrobenzene (mg/L)	0.00066, J	—
RDX (mg/L)	0.090, X	—
$\delta^{15}N$ (‰)	—	+9.6

Note: The data in this table should be used only for screening purposes. U means not detected. A dash in the table means, “not analyzed”. J means above instrument detection limit but less than practical quantitation limit. X means false positive based on reference spectra. ‰ means “per thousand."

Activities of americium-241, plutonium-238, plutonium-239,240, and strontium-90 are less than detection. Activities of uranium-234, uranium-235, and uranium-238 are 1.48, 0.126, and 1.41 pCi/L, respectively.

A borehole water sample collected at 1489 ft was analyzed for stable isotopes of nitrogen (N-15 and N-14) to evaluate the source(s) of nitrate at R-22. The $\delta^{15}N$ (NO_3) value is +9.6 permil (Table 13.2-1), suggesting that the water sample is enriched with nitrogen-15. Denitrification is a biochemical process occurring under anaerobic conditions and is catalyzed by denitrifying bacteria such as *Thiobacillus denitrificans*. Denitrification is the overall reduction of nitrate (N(V)), and various intermediate compounds such as nitric and nitrous oxides, to N_2 gas (N(0)). Denitrification produces positive $\delta^{15}N$ values (+3 to > +30‰) because ^{14}N is consumed (metabolized) by catabolic organisms. This denitrification results in enriched ^{15}N in the solid and liquid waste (manure) (Clark and Fritz, 1997, 59168). This isotopic value suggests that denitrification is occurring at the bottom of the borehole and that anaerobic conditions prevail at 1489 ft. Based on borehole water chemistry, the dominant reducing agents (electron donors) contributing to anaerobic conditions most likely include EZ-MUD® and QUIK-FOAM®.

Concentrations of bicarbonate, chloride, fluoride, and sulfate at the regional water table are 120, 21, 1.19, and 19.9 mg/L, respectively (Table 13.2-1). Concentrations of bromide (<0.20 mg/L), phosphate (as P) (<0.20 mg/L), and perchlorate (<1.04 µg/L) are less than detection.

Oxalate was detected in the borehole water sample, collected at 883 ft, at a concentration of 1.05 mg/L (Table 13.2-1). This compound may be produced by the breakdown of EZ-MUD®, which contains polyacrylate, a substituted carboxylate. Oxalate can occur naturally at very low concentrations (<0.02 mg/L) in groundwater and surface water around the Laboratory and elsewhere (Broxton et al. 2001, 66599). Methylene chloride (chloromethane) was also detected at 0.0046 mg/L (J value) (Table 13.2-1). It is a known chemical used in analytical laboratories for extraction during GC/MS analysis. Both compounds will be included in the analyte suite for characterization sampling in the completed well.

Analysis of the borehole water sample collected at 883 ft detected HE compounds and degradation products of TNT. Most significantly, hexahydro-1,3,5-trinitro-1,3,5-triazine (RDX) was detected at a concentration of 90 µg/L. This result is believed to be a false positive, based on similar chemical structures between RDX, including $C\text{-}N\text{-}NO_2$ functional group, and the polyacrylamide $((\text{-}CH_2CHCONH_2\text{-})_n)$-polyacrylate $((H_2C{=}CH\text{-}COO^-)_n)$ copolymers comprising EZ-MUD®. The compound 2-amino-4,6-dinitrotoluene (2-A-4,6DNT) was also detected above the instrument detection limit but below the practical reporting limit (J value) at the regional water table. The HPLC method (EPA SW846-8330) is susceptible to false positives, and, consequently, an alternative analytical method using diode array was used, which provides more accurate results. Paragon reran the borehole water sample using diode array, and HE compounds and degradation products were less than detection (0.25 µg/L).

The Groundwater Focus Area conducted an investigation to determine if EZ-MUD® and QUIK-FOAM® produce false positives for HE compounds and associated degradation products when analyzed by the EPA SW-846 Method 8330 (HPLC). EZ-MUD® and QUIK-FOAM® were added to deionized water to produce solutions containing 100, 500, and 1000 µg/L of the respective drilling fluids. The samples were submitted to GEL and Paragon Analytics, Inc. and analyzed for HE compounds and degradation products using HPLC with diode array detection. According to EPA Method 8330, an analyte is reported as a positive identification if there is a peak response within specified retention time windows. The diode array detector provides additional information for identification purposes by producing an absorption spectrum, which is then matched against a pure spectrum of the analyte stored in a spectrum library. The second column confirmation requirement in Method 8330 showed responses associated with various HE compounds, which were due to similarities in the C-N bonds in the EZ-MUD® (polyacrylamide). These responses resulted in false positives for HE compounds and degradation products. The diode array spectrums for these responses, however, did not produce a positive match when compared to the reference library spectrums, and therefore, no HE compounds were detected. This investigation demonstrated that EZ-MUD® produces false positives for several HE compounds, including RDX, TNT, 3-nitrotoluene, 2-amino-4,6-dinitrotoluene, and 4-amino-2,6-dinitrotoluene.

Additional groundwater samples will be collected during characterization in the completed well to evaluate the presence or absence of HE compounds at R-22.

13.3 Occurrence and Source of Acetone at R-22

During drilling, acetone was detected at the regional water table at R-22 at a concentration of 0.820 mg/L (Table 13.2-1). Presence of this organic compound may be due to oxidation of QUIK-FOAM®, which contains isopropyl alcohol. The following discussion presents results of confirmation sampling to determine the source(s) of acetone. The purpose of collecting confirmation samples was to evaluate the suspected presence of acetone identified in fractionation tanks (frac tanks) after completion of the drilling activities.

On October 16, 2000, water samples were collected from the injection water source (water used during well drilling), two frac tanks (tanks used to store the water produced during well drilling), and a trip blank. The results are presented in Table 13.3-1.

Table 13.3-1
Acetone Concentrations in Water Samples

Sample ID	Sample Description	Acetone Concentration (µg/L)
GW54-00-0017	Northern most frac tank	1700[a]
GW54-00-0019	Frac tank – 370	610
GW54-00-0021	Injection water	1500[a]
GW54-00-0021RR[b]	Injection water reanalysis	2100[a]
GW54-00-0022	Trip Blank	58

[a] Suspected false positive due to isopropyl alcohol.
[b] RR means reanalysis.

Based on the above analytical results, the largest concentration of acetone was present in the injection water. Based on these results, the following actions were performed.

- The mass spectra were requested from the analytical laboratory and were received on November 7, 2000.
- The distributors of the EZ-MUD *plus*® and the QUIK-FOAM® (Baroid) were contacted. Baroid stated that acetone was not used in any process to produce their products.
- From these preliminary results, a sampling analysis plan (SAP) was written to confirm the potential source of the acetone.

The following additional samples were taken on November 2, 2000.

- Two samples were taken from the injection water source (a fire hydrant just outside the TA-54 entrance gate). One sample was taken immediately after opening the valve and one was taken after five minutes of purging.
- One sample was taken from the truck used to haul and store the water during drilling activities.
- One sample was taken of the Baroid EZ-MUD *plus*® used during drilling.
- One sample was taken of the Baroid QUIK-FOAM® used during drilling.

- One sample was taken from each of the two additional frac-tanks that had not been previously sampled.
- One sample was taken from a frac-tank at a different drilling site (R-25) to be used as a background sample for the frac-tanks.

Sampling was accompanied with a series of blanks to measure potential background or laboratory contamination concentrations. Blank water was prepared before the sampling by using distilled water that was heated to a temperature of 85°C for one hour while purging with nitrogen.

- One blank was sealed and designated as the source blank water.
- One blank was designated as a sampling blank and opened during each sampling event.
- One blank was designated as a laboratory storage blank and opened in the lab storage area while samples were being stored awaiting analysis.
- One blank was designated as an analysis blank and opened in the analytical laboratory during the analysis of the samples.

Results of the confirmation samples are presented in Table 13.3-2.

Table 13.3-2
Acetone Concentrations in Water Samples

Sample ID	Sample Description	Acetone Concentration (μg/L)
GW54-00-0031	Source trip blank	ND[a]
GW54-00-0032	Travel trip blank	2
GW54-00-0033	Lab storage blank	ND
GW54-00-0034	Lab analysis blank	ND
GW54-00-0037	Hydrant immediate opening	ND
GW54-00-0038	Hydrant 5 minutes	ND
GW54-00-0039	Holding tank (truck)	ND
GW54-00-0040	EZ-MUD *plus*®	Polymerized, could not analyze
GW54-00-0041	Frac tank – 200	ND
GW54-00-0042	Frac tank – 371	24
GW54-00-0043	QUIK-FOAM®	2,090,000[b]
GWCV-00-0002	Frac tank at well R-25	ND

[a] ND = not detected.
[b] Suspected false positive due to isopropyl alcohol.

Based on this investigation, the mass spectra from the initial analysis showed that the injection water used during drilling at R-22 contained high concentrations of isopropyl alcohol, which was misidentified as acetone by Paragon Analytics, Inc. (See Table 13.3-2.). This finding was identified as a concern for the following reasons:

Analysis by GC/MS uses gas chromatography for analyte separation and mass spectrometry for qualification and quantification.

The molecular weights of acetone (58.08) and isopropyl alcohol (60.1) are very similar. These compounds will elute in nearly the same retention time on the typical GC/MS system following SW-846 Method 8260. Acetone is the compound of interest at R-22, whereas isopropyl alcohol is not.

The mass units for isopropyl alcohol are (m/z) 45, 43, 59, and 58. The mass units for acetone are 43 and 58. The mass spectrometer for qualification purposes uses the mass units and retention time. The analyte must elute in a certain retention time window and have the correct corresponding mass units for identification. The primary mass unit or primary ion is normalized at 100%, and the secondary and tertiary ions must be present in certain ratios to the primary ion for proper qualification.

For quantification purposes, the mass spectrometer uses the abundance of the primary ion only.

The problem arises that isopropyl alcohol has the same retention time and mass units very similar to acetone. The project team suspects that the results reported for acetone from the laboratory are false positives arising from the isopropyl alcohol. This view is supported by the mass spectral data. Acetone is being misidentified because the secondary ion for isopropyl alcohol is 43, which is the primary ion for acetone. The analysis of the QUIK-FOAM® confirms this suspicion.

The only positive mass spectra for acetone were identified in the frac-tanks 371 and 370. The project team believes the positive identification of acetone in the frac tanks is from a mild oxidation reaction, which converts isopropyl alcohol to acetone. The overall reaction is shown below:

$CH_3CHOHCH_3 + 0.5O_2 = (CH_3C)_2CO + H_2O$.

14.0 SUMMARY OF HYDROGEOLOGIC FEATURES AT SCREENED INTERVALS IN R-22

The five Westbay screened intervals in the completed well at R-22 include two zones in Cerros del Rio tholeiitic basalt, one in the upper Puye fanglomerates, one in the older basalt, and one in the lower Puye fanglomerates. Screen #1 spans the water level where saturation was first observed during drilling within the Cerros del Rio lavas. Screen #2 spans the static water level in drill hole that was cased to 1330-ft depth and open from 1330 ft to 1489 ft. Screen #3 is located within upper Puye fanglomerates that produced large amounts of water during drilling. Screen #4 is within heavily clay-altered older basalt that may produce very little water. Screen #5 is within a lower Puye fanglomerate that has about four times the clay content of the fanglomerate at screen #3 and thus may be less transmissive.

Screens #1 (872.3- to 914.2-ft depth) and #2 (947.0- to 988.9-ft depth) are both within the massive and relatively homogenous Cerros del Rio tholeiite that extends from 780 ft to 1165 ft at R-22. Both screens are in lava series without evidence for scoria in the cuttings samples. The most extensive scoria zone in this tholeiite is much deeper, at 1030- to 1056-ft depth. However, flow contacts and rubble zones between flows may still be a factor in transmission at both of these screens. Screen #1 crosses the upper transition into tholeiite of apparently higher lanthanide-element abundance and includes an interval (893 to 903 ft) where no cuttings were returned. Both features may indicate the presence of a rubble zone between flow units. Screen #2 lies just below the high-Gd tholeiite subzone. (See the interval in Figure 10.0-4 labeled “high Gd tholeiite.” The inference of lanthanide content is based on borehole-geophysics ECS Gd data.). The upper and lower boundaries of the lanthanide-rich tholeiite may be demarcated by flow-boundary rubble. Columnar fractures, entablature (subhorizontal) fractures, and flow-margin rubble all may contribute to groundwater flow at both screens. At both screens, the presence of relatively large amounts of ferrous iron (~7-8% FeO) may contribute to lower groundwater Eh.

Screen #3, at 1274.3- to 1281.0-ft depth within the upper Puye fanglomerates, is represented by the sample at 1273- to 1278-ft depth. The very minor clay content of this sample (4% of the 2- to 4-mm size fraction as shown in Table 10.3-3) and the abundance of unaltered glass (21%) are indications of generally unaltered deposits that are likely to be transmissive. Most of the glass in this sample is relatively pristine, with a glass alteration index [glass/(glass + clay)] of only 0.16 (Figure 10.0-5).

Screen #4 (1380.2- to 1386.9-ft depth) is within the older (pre-Cerros del Rio) basalt and is represented by the sample at 1377- to 1382-ft depth. High clay content (17%) in a dense nonporous host rock may make this a relatively tight horizon with little flow. In this altered sample, the oxidation-exsolution of iron oxides has been extensive, and the limited ferrous iron remaining (~2.5% FeO) may have little redox effect.

Screen #5, at 1449.1- to 1454.1-ft depth within the lower Puye fanglomerates, is represented by the sample at 1447 to 1452 ft. This fanglomerate sample is more clay-rich than the fanglomerate sample that represents Screen #3 (15% smectite vs. 4% smectite). Alteration is still largely incomplete, with a glass alteration index of only 0.31 (Figure 10.0-5). Quarterly sampling will determine whether this amount of alteration impacts flow at this screen.

15.0 IMPLICATIONS OF R-22 FOR CONCEPTUAL GEOLOGY, HYDROLOGY, AND GEOCHEMISTRY

The most prominent surprise at R-22 was the considerable thickness of Cerros del Rio lavas (Figure 10.0-3), which were almost three times as thick as predicted (983 ft vs. 339 ft). The upper tholeiitic to alkalic sequence of basalts (190- to 480-ft depth) can be provisionally correlated with similar sequences found at R-9, R-12, R-15, and in White Rock Canyon, making this sequence a regionally extensive component of the Geologic Model that can be traced beneath most of the northeastern Laboratory site. The most significant hydrogeologic impact of this thick set of Cerros del Rio lavas at R-22 is the placement of the regional water table within these lavas rather than within Puye fanglomerates. This change places all flow and transport within the upper ~300 ft of the regional aquifer within basaltic fractures and interflow rubble rather than through Puye pore spaces. Different flow rates and pathways are implied by this difference in stratigraphy. In addition, the Cerros del Rio lavas provide an environment in which constituents such as ferrous iron can influence water chemistry.

Beneath the Cerros del Rio lavas, the predicted stratigraphy included two units that were not encountered – axial river gravels of the Puye Formation (“Totavi” river gravels) and sediments of the Santa Fe Group (Figure 10.0-3). The reason that these units were predicted to occur can be seen in Figure 10.0-2. Two of the closest stratigraphic references for R-22 are at drill hole PM-2 and in an outcrop at White Rock Canyon. Projections from these references across the R-22 location predict intersection of both the Totavi and the Santa Fe Group.

The as-drilled stratigraphy at R-22 owes its peculiarities to several features. First and most important is the exceptional thickness of Cerros del Rio lavas and cinder, indicating fill within a paleocanyon. The absence of quartzite-rich axial river gravels at the base of this Cerros del Rio volcanic series suggests that this paleocanyon was not the path of a through-going drainage ancestral to the modern Rio Grande. It is important to note, however, that cuttings were not returned from ~51 ft of key intervals beneath the Cerros del Rio lavas. (No cuttings were returned at the 1178- to 1183-ft depth or at the 1191- to 1237-ft depth.) It is thus possible that quartzite-rich gravels may have been present within 5 ft of the base of the Cerros del Rio but were not sampled. As a result, it is uncertain whether the orientation of the paleocanyon may be more east-west (carved by flow from the volcanic highlands) than north-south (carved by rift-controlled flow). Whatever the orientation, the water table within the section shown in

Figure 10.0-2 is no longer entirely within sediments, as believed prior to R-22, but passes through a considerable mass of basalt between western source regions and the Rio Grande.

The older basalt at R-22, if related to the older basalt at R-9 of ~8.5 to 8.6 Ma age as expected, places a time horizon of considerable antiquity between two series of Puye fanglomerates that would otherwise be assumed in the present model to be no older than ~5 Ma. The presence of older "Puye"-like fanglomerates beneath this older basalt places coarse volcanic detritus from the west at a time and elevation where fine-grained detritus with a large plutonic or metamorphic component (Santa Fe Group) was previously presumed to occur. This finding calls into question some of the deeper stratigraphic contacts at PM-2 that have been described as Santa Fe Group deposits but are anomalous as such when compared to R-19 and R-22. Future drilling should be able to resolve this problem.

16.0 ACKNOWLEDGMENTS

The following organizations and individuals contributed to this investigation.

SG Western Construction constructed the R-22 drill pad.

Stewart Brothers Drilling Company provided Phase I drilling services under the direction of Paul Garcia, the drilling supervisor. The driller was Stanley Johnson.

Dynatec Drilling, Inc., provided the Phase II drilling services under the direction of J. Eddy, the drilling supervisor. The drillers were L. Thoren, D. Wilson, G. Woodward, R. Brown, C. Howe, and S. Devers.

Horace Patillo was the site safety officer.

Stephen Francis was the host facility point of contact for administrative oversight for TA-54.

T. Ball and S. Pearson provided contract oversight for drilling activities and field support. L. Martinez and J. Duran provided technical support for drilling activities and field support.

S. Hagelberg, J. Valdez, and A. Garcia provided sample management support. B. Hardesty provided data management support for drilling, sampling, and well completion activities. M. Clevenger provided support for borehole material curation.

M. Everett, A. Crowder, R. Lawrence, P. Schuh, J. Jordan, B. Hovda, J. McDonald, and D. Frank provided field support for drilling, sampling, and well completion activities. A. Crowder and M. Everett provided geophysics and video logging with LANL-owned equipment. Roger Sitton and a team of technicians with Schlumberger provided contract downhole geophysical logging.

D. Larssen installed the Westbay sampling system.

D. Counce was the analyst for water chemistry analyses used for screening of groundwaters collected from saturated zones.

R. Bohn provided oversight for waste management, and R. Evans and M. Shepard provided support.

The groundwater integration team, led by C. Nylander, participated in the planning and evaluation of data collected during this investigation.

G. Turner provided Department of Energy (DOE) oversight during the investigation.

J. Young of the New Mexico Environment Department (NMED) provided regulatory oversight during drilling operations. M. Dale from NMED's DOE Oversight Bureau collected sample splits from groundwater zones and acted as liaison with the regulators.

D. Broxton, J. McCann, and H. Wheeler-Benson were reviewers for the document.

C. Schaller was editor for this document. P. Maestas was compositor.

D. Daymon and J. McCann supported all phases of this investigation as leaders of the Groundwater Investigations Focus Area.

17.0 REFERENCES

ASTM (American Society for Testing and Materials), 1994. "ASTM Standards on Groundwater and Vadose Zone Investigations," sponsored by ASTM Committee on Rock and Soil (D-18), Philadelphia, Pennsylvania. (ASTM 1994)

ASTM (American Society for Testing and Materials), 2000. C150-00a "ASTM Standard Specification for Portland Cement," developed by ASTM Subcommittee: C01.01, West Conshohocken, Pennsylvania. (ASTM 2000)

Broxton, D. E., R. H. Gilkeson, P. A. Longmire, J. Marin, R. G. Warren, D. T. Vaniman, A. J. Crowder, B. D. Newman, B. Lowry, W. Stone, G. WoldeGabriel, D. Daymon, and D. Wycoff, May 2001. "Characterization Well R-9 Completion Report," Los Alamos National Laboratory Report LA-13742-MS, Los Alamos, New Mexico. (Broxton et al. 2001, 66599).

Broxton, D. E., and S. L. Reneau, August 1995. "Stratigraphic Nomenclature of the Bandelier Tuff for the Environmental Restoration Project at Los Alamos National Laboratory," Los Alamos National Laboratory Report LA-13010-MS, Los Alamos, New Mexico. (Broxton and Reneau, 1995, 49726)

Broxton, D. E., D. Vaniman, W. Stone, S. McLin, J, Marin, R. Koch, R. Warren, P. Longmire, D. Rogers, and N. Tapia, May 2001. "Characterization Well R-19 Completion Report," Los Alamos National Laboratory Report LA-13823-MS, Los Alamos, New Mexico. (Broxton et al. 2001, 66603)

Clark, I. D., and P. Fritz, 1997. Environmental Isotopes in Hydrogeology, Lewis Publishers, New York, New York. (Clark and Fritz 1997, 59168)

Dethier, D. P., 1997. "Geology of White Rock Quadrangle, Los Alamos and Santa Fe Counties, New Mexico," New Mexico Bureau of Mines and Mineral Resources, Geologic Map 73, 1:24,000, Socorro, New Mexico. (Dethier 1997, 49843)

Kendall, C., and T. B. Coplen, 1985. "Multisample Conversion of Water to Hydrogen by Zinc for Stable Isotope Determination," Anal. Chem., 57, 1437-1446 (1985).

LANL (Los Alamos National Laboratory), January 31, 1996. "Groundwater Protection Management Program Plan," rev. 2.0, Los Alamos, New Mexico. (LANL 1996, 70215)

LANL (Los Alamos National Laboratory), May 22, 1998. "Hydrogeologic Workplan," Los Alamos, New Mexico. (LANL 1998, 59599)

Rogers, D. B., and B. M. Gallaher, September 1995. "The Unsaturated Hydraulic Characteristics of the Bandelier Tuff," Los Alamos National Laboratory Report LA-12968-MS, Los Alamos, New Mexico. (Rogers and Gallaher 1995, 55334)

Shurbaji, A. R., and A. R. Campbell, February 1997. "Study of Evaporation and Recharge in Desert Soil Using Environmental Tracers, New Mexico USA," in Environ. Geol., 29, 147-151 (1997). (Shurbaji and Campbell 1997, 64063)

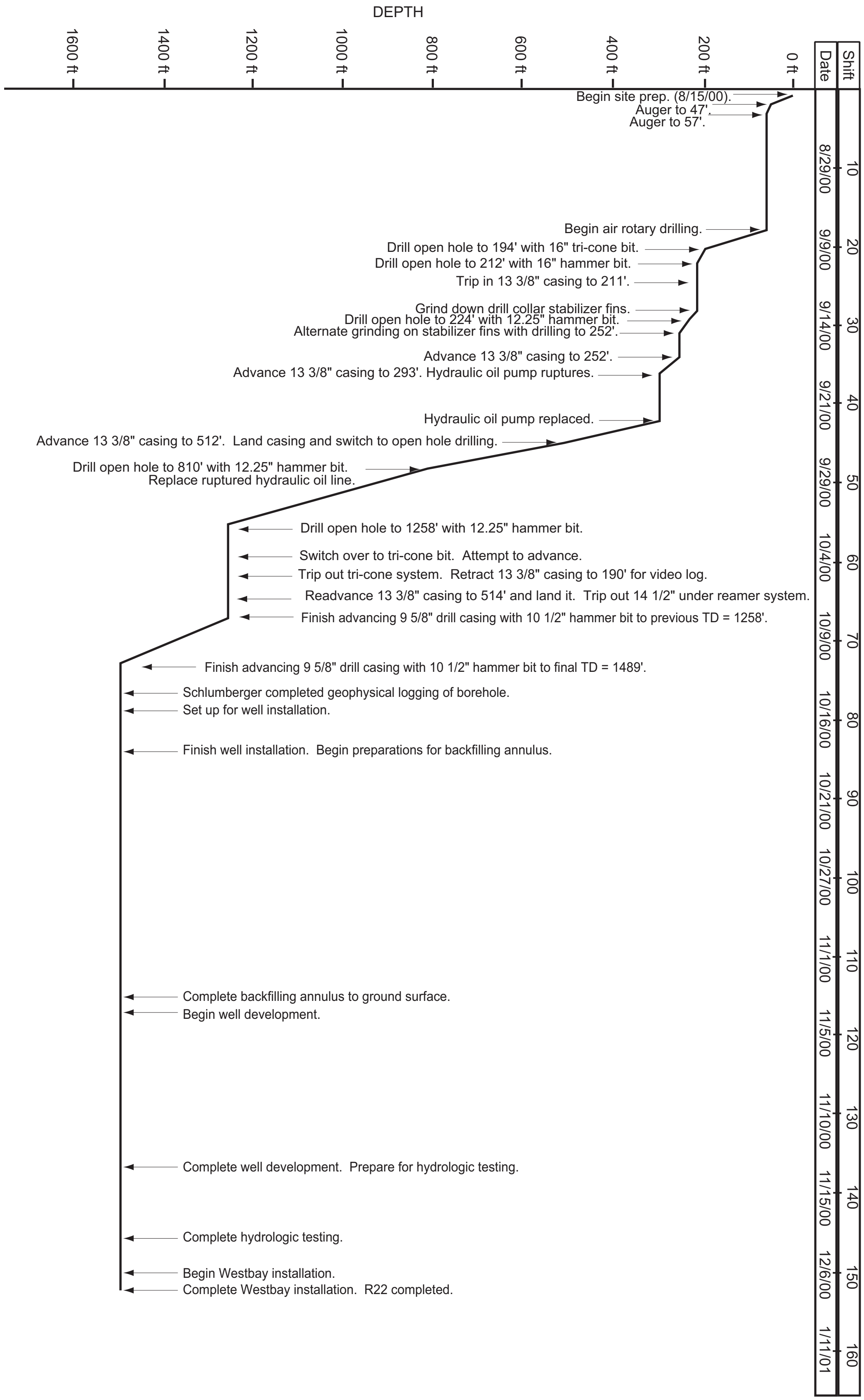
Socki, R. A., H. R. Karlsson, and E. K. Gibson, 1992. "Extraction Technique for Determination of Oxygen-18 in Water Using Preevacuated Glass Vials," Anal. Chem., 64, 829-831 (1992). (Socki et al. 1992, 64064)

Stone, W., S. McLin, and D. Vaniman, 2001. "Hydraulic Conductivity vs. Geology in New Los Alamos Wells" (abstract), New Mexico Geological Society Spring Meeting Abstracts, p. 32. (Stone et al. 2001, 70090)

WoldeGabriel, G., A.W. Laughlin, D.P. Dethier, and M. Heizler, 1996. "Temporal and Geochemical Trends of Lavas in White Rock Canyon and the Pajarito Plateau, Jemez Volcanic Field, New Mexico, USA," New Mexico Geological Society Guidebook, 47th Field Conference, pp. 251-261. (WoldeGabriel et al. 1997, 54427)

Appendix A

Diagram of Site Activities Related to Progress



APPENDIX A DIAGRAM OF SITE ACTIVITIES RELATED TO PROGRESS

Appendix B

Activities Planned for R-22 Compared with Work Performed

APPENDIX B ACTIVITIES PLANNED FOR R-22 COMPARED WITH WORK PERFORMED

Activity	Work Plan for Pajarito Canyon	Hydrogeologic Work Plan	R-22 Field Implementation Plan	R-22 Actual Work
Planned Depth	Refers to hydrogeologic work plan	100 to 500 ft into the regional aquifer (1100 to 1600 ft)	Nominally 1500 ft	Total drill depth: 1489 ft bgs.
Drilling Method	Auger or rotary drilling	Methods may include, but are not limited to HSA, air-rotary/Odex/Stratex, air-rotary/Barber rig, mud-rotary drilling	Air rotary methods	HSA drilling from 0 to 47 ft. Fluid-assisted air-rotary RC drilling w/casing advance from 47 to 1489 ft.
Amount of Core	Refers to hydrogeologic work plan	100 percent	Implemented as deemed necessary	No core drilling attempted
Lithologic Log	Log to be prepared from core, cuttings, drilling performance	Log to be prepared from core	Log to be prepared from core, cuttings, geophysical logs and drilling performance	Lithologic log of drill cuttings from 0 to 1489 ft.
Number of Water Samples Collected for Contaminant Analysis	A water sample to be collected from each saturated zone. Well to be sampled at completion and at six month intervals for two years	A water sample may be collected from each saturated zone, five zones assumed. Number of sampling events after well completion not specified	A water sample will be collected from each saturated zone. The geochemistry project leader and technical team will determine the number and locations of samples based on conditions encountered. The number of sampling events after well completion is not specified. Up to six water samples are planned.	One saturated zone encountered – regional water table at 883 ft bgs. Two (2) water samples collected for laboratory analysis during the drilling phase at depths of 883 ft and 1489 ft bgs.

Activity	Work Plan for Pajarito Canyon	Hydrogeologic Work Plan	R-22 Field Implementation Plan	R-22 Actual Work
Water Sample Analysis	**Trace Elements/Metals:** Al, Sb, As, Ba, Be, B, Cd, Ca, Cr, Co, Cu, Fe, Pb, Mg, Hg, Ni, K, Se, Ag, Na, Tl, Ti, U, V, Zn **Anions:** Br, ClO_3, Cl,F, NO_3, PO_4, HCO_3, SO_4 **Other Inorganic Chemicals:** Si, cyanide **Stable and Radiogenic Isotopes:** ^{14}C, ^{13}C, ^{36}Cl, D/H, $^{18}O/^{16}O$ **Radionuclides:** ^{3}H, ^{90}Sr, ^{137}Cs, ^{234}U, ^{235}U, ^{238}U, ^{238}Pu, $^{239,240}Pu$, ^{241}Am, gamma spectrometry, gross alpha, beta, gamma **Organic Compounds:** pesticides, polychlorinated biphenyls (PCBs), VOCs, SVOCs, HE, dissolved organic carbon	Metals, radiochemistry I, II, and III, gamma spectrometry, general inorganics, Appendix VIII and IX organic compounds, stable isotopes, tritium	**Trace Elements/Metals,** **Anions:** Br, Cl, Fl, PO_4, SO_4, NO_3, NO_2, NH_4 **Major Cations,** **Other Inorganic Chemicals: cyanide** **Stable and Radiogenic Isotopes:** $^{18}O/^{16}O$, D/H, $^{15}N/^{14}N$ **Radionuclides:**^{3}H, ^{90}Sr, ^{241}Am, ^{137}Cs, ^{238}Pu, $^{239,240}Pu$, ^{234}U, ^{235}U, ^{238}U, gamma spectrometry, gross-alpha, gross-beta, gross gamma, total uranium by ICPMS, total uranium by KPA **Organic Compounds:** VOCs, polycyclic aromatic hydrocarbons, pesticides/PCBs, HE, humic acid, total organic carbon	Sample @ 883' **Anions,** **Perchlorate,** **Radionuclides** ^{235}U, ^{238}U, ^{238}Pu, $^{239,240}Pu$, ^{90}Sr, ^{241}Am, gamma spectroscopy **Isotopes** $^{15}N/^{14}N$ **HE** **Volatile Organic Analyses (VOAs) w/ Tentatively Identified Compounds (Tics)** **Semi-VOAs w/Tics** **Low-level ^{3}H** Sample @ 1489' **Isotopes** $^{15}N/^{14}N$ **Low-level ^{3}H**
Water Sample Field Measurements	Alkalinity, dissolved oxygen, pH, specific conductance, temperature, turbidity	Alkalinity, pH, specific conductance, temperature, turbidity	Specific conductance, pH, temperature, turbidity	Not measured due to equipment breakdown in the field
Number of Core/Cuttings Samples Collected for Contaminant Analysis	Collect and preserve 13 cores to represent major hydrogeologic units and zones above and below major hydrogeologic contacts	Twenty samples of core or cuttings to be analyzed for contaminants in each borehole	Up to 37 core/cuttings samples planned. Number of samples dependant on number of saturated zones encountered	No core or cuttings samples submitted for laboratory analysis

Activity	Work Plan for Pajarito Canyon	Hydrogeologic Work Plan	R-22 Field Implementation Plan	R-22 Actual Work
Core Sample Analytes	**Trace Elements/Metals:** Al, Sb, As, Ba, Be, B, Cd, Cr, Co, Cu, Fe, Pb, Mg, Hg, Ni, Se, Ag, Na, Tl, Ti, U, V, Zn **Anions:** Br, Cl, F, SO_4 **Other Inorganic Chemicals:** cyanide **Stable and Radiogenic Isotopes:** ^{14}C, ^{13}C, ^{36}Cl, D/H, $^{18}O/^{16}O$ **Radionuclides:** ^{3}H, ^{90}Sr, ^{137}Cs, ^{234}U, ^{235}U, ^{238}U, ^{238}Pu, $^{239,240}Pu$, ^{241}Am, gamma spectrometry, gross alpha, beta, gamma **Organic Compounds:** pesticides, PCBs, SVOCs, HE, TOC	Uppermost sample to be analyzed for a full range of compounds; deeper samples to be analyzed for the presence of radiochemistry I, II, and III analytes, tritium, and metals Four samples to be analyzed for VOCs.	**Trace Elements/Metals,** **Anions,** **Radionuclides:** ^{3}H, ^{90}Sr, ^{137}Cs, ^{234}U, ^{235}U, ^{238}U, ^{238}Pu, $^{239,240}Pu$, gamma spectrometry, gross alpha, gross beta, gross gamma **Organic Compounds:** VOCs, SVOCs	No core samples collected. No samples submitted for analysis
Laboratory Hydraulic-Property Tests	Selected borehole core samples will be analyzed for bulk density, porosity, moisture content, moisture potential, saturated hydraulic conductivity	Physical properties to be determined on 5 samples and will typically include: moisture content, porosity, particle density, bulk density, saturated hydraulic conductivity, and water retention characteristics	Selected unsaturated materials may be tested in the laboratory for the full suite of hydraulic properties.	No core samples were collected. No samples were submitted for analysis.
Geology	Refers to hydrogeologic work plan	Approximately 10 samples of core or cuttings will be collected for mineralogy, petrography, and rock chemistry.	The geology task leader will determine the number of samples for characterization of mineralogy, petrography, and rock chemistry based on geologic and hydrologic conditions encountered during drilling	Twenty-eight (28) cuttings samples were submitted for geologic characterization.

Activity	Work Plan for Pajarito Canyon	Hydrogeologic Work Plan	R-22 Field Implementation Plan	R-22 Actual Work
Geophysics	Refers to hydrogeologic work plan	In general, open-hole geophysics includes caliper, electromagnetic induction, natural gamma, magnetic susceptibility, borehole color videotape, fluid temperature (saturated), single-point resistivity (saturated), and spontaneous potential (saturated). In general, cased-hole geophysics includes: gamma-gamma density, natural gamma, and thermal neutron.	In general, open-hole geophysics includes caliper, electromagnetic induction, natural gamma, magnetic susceptibility, borehole color videotape, fluid temperature (saturated), fluid resistivity (saturated), and spontaneous potential (saturated). In general, cased-hole geophysics includes: gamma-gamma density, natural gamma, and thermal neutron.	Geophysical logs performed: LANL- Video logs (2), Natural Gamma Schlumberger contract- Neutron Porosity, Spectral Gamma, Gamma-Gamma, Density, Elemental Capture Spectroscopy. (Refer to R-22 fact sheet for further details regarding cased and open-hole intervals.)
Water-Level Measurements			Water levels will be determined for each saturated zone by water-level meter or by pressure transducer. Additional water-level readings are to be made at as many borehole depths as possible for vertical gradient determination.	<u>One</u> saturated zone (regional water table) was encountered. Depth to water to the top of the water table confirmed at approximately 883 ft bgs based on a series of four concurring water-level measurements made at the time groundwater was first encountered during drilling
Field Hydraulic-Property Tests			Slug or pumping tests may be conducted in saturated intervals once the well is completed.	Slug tests conducted for screens 2, 3, 4, and 5
Surface Casing	Refers to hydrogeologic work plan	Approximately 20-in. O.D., extends from land surface to 10-ft depth in underlying competent layer and grouted in place	16-in. diameter mild steel casing set to a depth of 37 ft	18-in. diameter surface casing from 0 to 47 ft bgs.

Activity	Work Plan for Pajarito Canyon	Hydrogeologic Work Plan	R-22 Field Implementation Plan	R-22 Actual Work
Minimum Well Casing Size	Refers to hydrogeologic work plan	6 5/8-in. O.D.	5.56-in. O.D.	Well casing used: 5.0-in. O.D. (4.5-in. I.D.) stainless steel with external couplings
Well Screen	Refers to hydrogeologic work plan	Machine-slotted (0.01-in.) stainless steel screens with flush-jointed threads. The number and length of screens to be determined on a site-specific basis and proposed to NMED	Five screens ranging from 10 to 25 ft in length; wire-wrapped 304 stainless-steel screens with 0.010-in. gaps	Screen materials used: 4.5-in. I.D. stainless-steel, wire-wrapped, 0.010-in. slotted, with exterior couplings
Filter Material	Refers to hydrogeologic work plan	>90% silica sand, properly sized for the 0.010-in. slot size of the well screen; extends 2 ft above and below the well screen	Primary filter pack is coarse (20-40), silica sand with a uniformity coefficient of 2.0 or less, placed 10 ft above and below screen. Secondary filter pack is finer (30-70) silica sand placed 3 ft below and 5 ft above the primary pack	Primary filter pack: 6/9 silica sand 8/12 silica sand Secondary filter pack: 20/40 silica sand 30/70 silica sand (Refer to R-22 as-built diagram for specific silica sand intervals at each screen.)

Activity	Work Plan for Pajarito Canyon	Hydrogeologic Work Plan	R-22 Field Implementation Plan	R-22 Actual Work
Conductor Casing	Refers to hydrogeologic work plan	Carbon-steel casing from land surface to top of stainless-steel casing	Carbon-steel casing 5.56-in. in diameter extending from land surface to dielectric coupling at top of stainless-steel casing	18-in. steel surface casing from 0 to 47 ft bgs.
Backfill Material (exclusive of filter materials)	Refers to hydrogeologic work plan	Uncontaminated drill cuttings below sump and bentonite above sump	Bentonite in borehole below well; fine sand in transition zone; bentonite above transition zone to bottom of surface casing; cement grout between surface casing and borehole wall and between surface casing and well casing	Materials used: bentonite (chips or pellets) between gravel pack intervals, bentonite and gravel (50/50 mix) above screen #1, neat cement grout in selected intervals for structural stability and from 0 to 75 ft. (Refer to R-22 as-built diagram for specific bentonite and cement grout intervals.)
Sump	Refers to hydrogeologic work plan	Stainless-steel casing with an end cap	5.56-in. diameter stainless-steel casing 30 ft long	A 20-ft-long sump constructed below screen 5 consists of 5.0-in. stainless-steel casing and welded steel end cap.
Bottom Seal	Refers to hydrogeologic work plan	Bentonite	Bentonite	No bottom seal constructed due to sloughing and unstable formation at the bottom of the borehole

Appendix C

Lithologic Log

LOS ALAMOS NATIONAL LABORATORY
ENVIRONMENTAL RESTORATION PROJECT,
GROUND WATER INVESTIGATIONS FOCUS AREA
BOREHOLE LOG

BOREHOLE ID: R-22	TA/OU: TA-54	Page 1 of 21
DRILLING COMPANY: Stewart Bro./Dynatec	Start Date: 9/00	Finish Date: 11/00
DRILLING EQ/METHOD: CME-750/Foremost DR24		SAMPLING EQ/METHOD: Cuttings
GROUND ELEVATION: 6650.5 ft		TOTAL DEPTH = 1489 ft bgs
DRILLER: Johnson/Thoren, Wilson, Woodward		GEOLOGY P.I.: Vaniman

Depth (ft)	Elevation (ft)	Core Run # (amt.-recov./amt. attemp.)	Core Run	Cuttings Collected	Geologic Characterization (Depth Interval)	Moisture/Matric Pot.	Lithology	Graphic Log	Lithologic Symbol
0–75	6650–6575	No core attempted.				No samples collected			
0	6650						Qbt 2 TSHIREGE MEMBER, BANDELIER TUFF: (0-5 ft) Volcanic tuff, grayish orange pink (5YR 7/2)-whole rock, pumice fragments up to 3 mm length; aspect ratio of 3:1; 5% sanidine phenocrysts <1%, 10% mafic phenocrysts up to 1 mm.		Qbt 2
5	6645						Qbt 2 TSHIREGE MEMBER, BANDELIER TUFF: (5-15 ft) Volcanic tuff, pale red (10YR 6/2) whole rock, pumice fragments are pale brown (5YR 5/2), up to 3 mm, aspect ratio 3:1, 20% pumice fragments; 5% sanidine up to 2 mm, <1-2% mafics, v. fine grained.		Qbt 2
15	6635						Qbt 2 TSHIREGE MEMBER, BANDELIER TUFF: (15-44 ft) Volcanic tuff, soft, matrix grayish red (5YR 3/2), pumice fragments grayish brown (5YR 3/2) and up to 5 mm in length, aspect ratio 5:2, 5% pumice, 10-20% sanidine and quartz phenocrysts up to 3 mm.		Qbt 2
44							Qbt 1v TSHIREGE MEMBER, BANDELIER TUFF: (44-47 ft) Volcanic tuff, pinkish gray (5YR 8/1) matrix with 10% moderate yellowish brown (10YR 5/4) pumice, less welded, up to 4 mm, aspect ratio 4:3, 10-20% coarse phenocrysts up to 3 mm of sanidine and quartz .		Qbt 1v
47							Qbt 1v TSHIREGE MEMBER, BANDELIER TUFF: (47-57 ft) Volcanic tuff, grayish red (5YR 4/2) matrix with 15% brownish gray (5YR 4/1) pumice fragments, 1 cm in length, aspect ratio of 2:1, subrounded, 10% sanidine and quartz phenocrysts up to 1 mm.		Qbt 1v
57							Qbt 1v TSHIREGE MEMBER, BANDELIER TUFF: (57-67 ft) Volcanic tuff with dacite xenoliths, moderately hard, 1(sanidine up to 2 mm, <2% mafics up to 1 mm; <1% pumice; dacite has filled-in fractures.		Qbt 1v
67							Qbt 1v TSHIREGE MEMBER, BANDELIER TUFF: (67-77 ft) Volcanic tuff, soft to moderately hard, grayish orange pink (5YR 7/2) to mod. orange pink (5YR 8/4); 20-25% volcanic glass; sample is equally ash and pumice; unable to determine aspect ratios (due to large pumice size); 10-15% quartz and sanidine; 2-3% mafics; also contains dacitic fragments, pale yellowish brown (10YR 6/2). Based on presence of volcanic glass, the Qbt 1v/Qbt 1g contact occurs between 72 and 82 ft.		Qbt 1v

Depth scale (ft): 0, 5, 10, 15, 20, 25, 30, 35, 40, 45, 50, 55, 60, 65, 70, 75
Elevation scale (ft): 6650, 6645, 6640, 6635, 6630, 6625, 6620, 6615, 6610, 6605, 6600, 6595, 6590, 6585, 6580, 6575

LOS ALAMOS NATIONAL LABORATORY
ENVIRONMENTAL RESTORATION PROJECT,
GROUND WATER INVESTIGATIONS FOCUS AREA
BOREHOLE LOG

BOREHOLE ID: R-22	TA/OU: TA-54	Page 2 of 21
DRILLING COMPANY: Stewart Bro./Dynatec	Start Date: 9/00	Finish Date: 11/00
DRILLING EQ/METHOD: CME-750/Foremost DR24		SAMPLING EQ/METHOD: Cuttings
GROUND ELEVATION: 6650.5 ft		TOTAL DEPTH = 1489 ft bgs
DRILLER: Johnson/Thoren, Wilson, Woodward		GEOLOGY P.I.: Vaniman

Depth (ft)	Elevation (ft)	Core Run # (amt.-recov./amt. attemp.)	Core Run	Cuttings Collected	Geologic Characterization (Depth Interval)	Moisture/Matric Pot.	Lithology	Graphic Log	Lithologic Symbol
80	6565						Qbt 1g TSHIREGE MEMBER, BANDELIER TUFF: (77-82 ft) Rhyolitic pumice, grayish-orange pink (5YR 7/2); vitreous; fibrous texture; <1% mafics, up to <1mm		
85	6560						Qbt 1g TSHIREGE MEMBER, BANDELIER TUFF: (82-87 ft) Volcaniclastics, grayish orange pink (5YR 7/2) to pale brown (5YR 5/2) to light gray (N7); small gravel (3/4" diameter); lithics comprised of siliceous tuff and intermediate to siliceous volcanic rocks; angular to subrounded; tuff gravels with 10-15% sanidine and quartz, <5% mafic minerals, <5% pumice		
90	6555								
95	6550								
100	6545						Qbt 1g TSHIREGE MEMBER, BANDELIER TUFF: (87-97 ft) Rhyolitic pumice, light brownish gray (5YR 6/1); vitreous; fibrous texture; 20-30% sanidine and quartz, <1% mafics, 5% lithics		Qbt 1g
105	6540								
110	6535						Qbt 1g TSHIREGE MEMBER, BANDELIER TUFF: (97-128 ft) Volcanic tuff; soft to moderately hard; pinkish gray pumice (5YR 8/1); 20-30% vitreous pumice (large pieces) >15 mm, 10% sanidine and quartz (subangular to subrounded); 5-10% lithics; 1-2% mafics.		
115	6530								
120	6525								
125	6520								
130	6515						Qbo OTOWI MEMBER, BANDELIER TUFF: (128-144 ft) Volcanic tuff; moderate yellowish brown (10YR 5/4) matrix, pumices are 10YR 8/6, 10% glass, sanidine, and quartz up to 1mm, 10% white, light pink, and orange pumice fragments up to 1 cm, some fragments with vitreous luster, 5% mafics up to 1 mm		
135	6510								
140	6505								
145	6500								Qbo
150	6495								
155	6490								
160	6485								
165	6480								

LOS ALAMOS NATIONAL LABORATORY
ENVIRONMENTAL RESTORATION PROJECT,
GROUND WATER INVESTIGATIONS FOCUS AREA
BOREHOLE LOG

BOREHOLE ID: R-22	TA/OU: TA-54	Page 3 of 21
DRILLING COMPANY: Stewart Bro./Dynatec	Start Date: 9/00	Finish Date: 11/00
DRILLING EQ/METHOD: CME-750/Foremost DR24		SAMPLING EQ/METHOD: Cuttings
GROUND ELEVATION: 6650.5 ft		TOTAL DEPTH = 1489 ft bgs
DRILLER: Johnson/Thoren, Wilson, Woodward		GEOLOGY P.I.: Vaniman

Depth (ft)	Elevation (ft)	Core Run # (amt.-recov./amt. attemp.)	Core Run	Cuttings Collected	Geologic Characterization (Depth Interval)	Moisture/Matric Pot.	Lithology	Graphic Log	Lithologic Symbol
170	6480						Qbo OTOWI MEMBER, BANDELIER TUFF: (144-169 ft) Volcanic tuff; moderate yellowish brown (10YR 5/4) matrix, 10% glass, sanidine, and quartz up to 1 mm, 10% white, light pink, and orange pumice fragments up to 1 cm, some fragments with vitreous luster, 5% mafics up to 1 mm.		Qbo
175	6475								
180	6470						Qbo OTOWI MEMBER, BANDELIER TUFF: (169-179 ft) Volcanic tuff; moderate yellowish brown (10YR 5/4) matrix, phenocrysts of glass and sanidine up to 1 mm, 15-20% pumice, white, light gray, dark gray and orange, subangular to subrounded, up to 1.8 cm.		Qbog
185	6465								
190	6460						Qbog GUAJE PUMICE BED: (179-190 ft) Pumice, light brownish gray (5YR6/1), <5% glass, <2% mafics, pumice fragments, white to light gray, subangular, up to 1.5 cm.		
195	6455						CERROS DEL RIO BASALT: (190-197 ft) Sand, pale orange (10YR8/2), fine to coarse sand, clasts angular to subrounded w/up to 3 mm grains consisting of glass, sanidine, pumice, and basalt pebbles; transition zone to Tb4.		
200	6450								
205	6445								Tb4
210	6440						CERROS DEL RIO BASALT: (197-202 ft) Gravelly sand, very pale orange (10YR8/2), subangular to subrounded grains, gravel consists of 50-60% basalt, 30-40% pumice up to 1.5 mm, >35 mesh grains consist of basalt, sanidine, and pumice.		
215	6435				Geologic (217-222 ft)				
220	6430						CERROS DEL RIO BASALT: (202-207 ft) Gravel, subangular to subrounded, 70% basalt, dark gray (N3), 30% pumice, very pale orange (10YR8/2) up to 1.6 mm, basalt has sm. amt. of angular vesicles, several filled with CaCO3 , sm. amt. of olivine phenocrysts.		
225	6425						CERROS DEL RIO BASALT: (207-212 ft) Basalt, med. dark gray (N4), w/ rounded to angular vesicles up to 5 mm across,olivine phenocrysts, quartz xenocrysts, $CaCO_3$ coating and oxidation on most particles.		
							CERROS DEL RIO BASALT: (212-222 ft) Basalt, 5% small round vesicles, slight $CaCO_3$, olivine phenocrysts, quartz (?).		
							CERROS DEL RIO BASALT: (222-227 ft) No sample recovery.		

LOS ALAMOS NATIONAL LABORATORY
ENVIRONMENTAL RESTORATION PROJECT,
GROUND WATER INVESTIGATIONS FOCUS AREA
BOREHOLE LOG

BOREHOLE ID: R-22	TA/OU: TA-54	Page 4 of 21
DRILLING COMPANY: Stewart Bro./Dynatec	Start Date: 9/00	Finish Date: 11/00
DRILLING EQ/METHOD: CME-750/Foremost DR24		SAMPLING EQ/METHOD: Cuttings
GROUND ELEVATION: 6650.5 ft		TOTAL DEPTH = 1489 ft bgs
DRILLER: Johnson/Thoren, Wilson, Woodward		GEOLOGY P.I.: Vaniman

Depth (ft)	Elevation (ft)	Core Run # (amt.-recov./amt. attemp.)	Core Run	Cuttings Collected	Geologic Characterization (Depth Interval)	Moisture/Matric Pot.	Lithology	Graphic Log	Lithologic Symbol
230	6420						CERROS DEL RIO BASALT: (227-237 ft) Basalt med. dark gray (N4), few or no vesicles, olivine phenocrysts, quartz xenocrysts (?)		
235	6415								
240	6410						CERROS DEL RIO BASALT: (237-242 ft) Basalt, dark gray (N3), vesicular w/ oxidation.		
245	6405						CERROS DEL RIO BASALT: (242-247 ft) Basalt, med. gray (N5), vesicular, porphyritic w/aphanitic groundmass, phenocrysts of plagioclase (2.5 mm), pyroxene, olivine >10% by volume, local Fe/Mn oxides coating vesicles.		
250	6400								
255	6395						CERROS DEL RIO BASALT: (247-252 ft) Basalt, reddish brown (5YR4/4), scoriaceous to massive, v. strong oxidation coating vesicles.		
260	6390						CERROS DEL RIO BASALT: (252-257 ft) Basalt, med. gray (N4), vesicular to massive, phenocrysts of feldspar and olivine (1-2 mm) >10% by volume.		
265	6385								
270	6380						CERROS DEL RIO BASALT: (257-272 ft) No sample recovery.		Tb4
275	6375						CERROS DEL RIO BASALT: (272-277 ft) Basalt, slightly vesicular, vesicles are oxidized, olivine phenocrysts.		
280	6370								
285	6365						CERROS DEL RIO BASALT: (277-282 ft) No sample recovery.		
290	6360						CERROS DEL RIO BASALT: (282-287 ft) Basalt; slightly vesicular, vesicles up to 1 mm long, calcite (?), oxidized, olivine phenocrysts up to 1 mm.		
295	6355						CERROS DEL RIO BASALT: (287-316 ft) No sample recovery.		
300	6350								
305	6345								
310	6340								
315	6335								

LOS ALAMOS NATIONAL LABORATORY
ENVIRONMENTAL RESTORATION PROJECT,
GROUND WATER INVESTIGATIONS FOCUS AREA
BOREHOLE LOG

BOREHOLE ID: R-22	TA/OU: TA-54	Page 5 of 21
DRILLING COMPANY: Stewart Bro./Dynatec	Start Date: 9/00	Finish Date: 11/00
DRILLING EQ/METHOD: CME-750/Foremost DR24	SAMPLING EQ/METHOD: Cuttings	
GROUND ELEVATION: 6650.5 ft DRILLER: Johnson/Thoren, Wilson, Woodward		TOTAL DEPTH = 1489 ft bgs GEOLOGY P.I.: Vaniman

Depth (ft)	Elevation (ft)	Core Run # (amt.-recov./amt. attemp.)	Core Run	Cuttings Collected	Geologic Characterization (Depth Interval)	Moisture/Matric Pot.	Lithology	Graphic Log	Lithologic Symbol
320	6330						CERROS DEL RIO BASALT: (316-317 ft) Basaltic fines, brownish-gray (5YR 4/4), >60 fraction only (spot sample), unidentified mafic minerals.		
325	6325						CERROS DEL RIO BASALT: (317-322 ft) Basalt, dark gray (N4), strongly vesicular to scoriaceous, vesicles lined w/ pale reddish Fe/Mn oxides and/or tan secondary silica (?).		
330	6320						CERROS DEL RIO BASALT: (322-327 ft) Basalt, med. gray (N5), vesicular to massive, phenocrysts (<10% by volume) of green olivine and brown pyroxene; euhedral to rounded plagioclase laths; aphanitic groundmass.		
335	6315						CERROS DEL RIO BASALT: (327-332 ft) Basalt, med. gray (N5), weak to strongly vesicular, prominent large phenocrysts of dk. brown, euhedral olivine, locally twinned growths; vesicles commonly lined w/ white silica (?) and/or tan clay.		
340	6310						CERROS DEL RIO BASALT: (332-337 ft) Basalt, dark gray, aphanitic, aphyric. Locally scoriaceous and strongly oxicized. The oxidized portion dominates in volume.		Tb4
345	6305						CERROS DEL RIO BASALT: (337-340 ft) Basalt, dominately scoriaceous, strongly oxidized, w/ locally abundant soft tan clay lining vesicles; lesser amounts of massive to weakly vesicular basalt, containing <10% phenocrysts olivine. Lost circulation at 340'.		
350	6300						CERROS DEL RIO BASALT: (340-349 ft) No sample recovery.		
355	6295						CERROS DEL RIO BASALT: (349-352 ft) Basalt, massive to weakly vesicular, <5% mafic phenocrysts, aphanitic groundmass, local Fe/Mn oxides coating vesicles; local/minor botriodal/amorphous silica, white grains of possible zeolite.		
360	6290						CERROS DEL RIO BASALT: (352-357 ft) Basalt, strongly vesicular to scoriaceous, locally strong Fe/Mn oxides lining of vesicles, local yellowish white silica fracture coating.		
365	6285						CERROS DEL RIO BASALT: (357-367 ft) Basalt, med. gray (N5), few vesicles, phenocrysts of feldspar and olivine.		

LOS ALAMOS NATIONAL LABORATORY
ENVIRONMENTAL RESTORATION PROJECT,
GROUND WATER INVESTIGATIONS FOCUS AREA
BOREHOLE LOG

BOREHOLE ID: R-22	TA/OU: TA-54	Page 6 of 21
DRILLING COMPANY: Stewart Bro./Dynatec	Start Date: 9/00	Finish Date: 11/00
DRILLING EQ/METHOD: CME-750/Foremost DR24		SAMPLING EQ/METHOD: Cuttings
GROUND ELEVATION: 6650.5 ft		TOTAL DEPTH = 1489 ft bgs
DRILLER: Johnson/Thoren, Wilson, Woodward		GEOLOGY P.I.: Vaniman

Depth (ft)	Elevation (ft)	Core Run # (amt.-recov./amt. attemp.)	Core Run	Cuttings Collected	Geologic Characterization (Depth Interval)	Moisture/Matric Pot.	Lithology	Graphic Log	Lithologic Symbol
370	6280						CERROS DEL RIO BASALT: (367-382 ft) Basalt, med. gray (N5), few vesicles, phenocrysts of feldspar, olivine, and pyroxene(?), some oxidation.		
375	6275				Geologic (377-382 ft)				
380	6270								
385	6265						CERROS DEL RIO BASALT: (382-387 ft) Basalt, med. gray (N5), few vesicles, phenocrysts of feldspar and olivine, very oxidized, no reaction to HCl.		
390	6260						CERROS DEL RIO BASALT: (387-402 ft) No sample recovery.		
395	6255								
400	6250								Tb4
405	6245						CERROS DEL RIO BASALT: (402-407 ft) Basalt, brownish gray (5YR4/1); moderately vesicular; 5% quartz, trace (<1%) olivine phenocrysts.		
410	6240						CERROS DEL RIO BASALT: (407-417 ft) Basalt, pale yellowish brown (10YR6/2); strongly vesicular to scoriaceous, moderately oxidized, 2-3% quartz and <1% olivine phenocrysts up to 1 mm.		
415	6235								
420	6230						CERROS DEL RIO BASALT: (417-432 ft) Basalt, brownish gray (5YR4/1); slightly to moderately vesicular; salt and pepper look; very fine-grained quartz and mafic minerals; <1% feldspars to 1 mm; slightly oxidized.		
425	6225				Geologic (427-432 ft)				
430	6220								
435	6215						CERROS DEL RIO BASALT: (432-437 ft) Basalt, brownish gray (5YR4/1); moderately to very vesicular; oxidized, 20-40% of vesicles filled w/ possible silicon.		

LOS ALAMOS NATIONAL LABORATORY
ENVIRONMENTAL RESTORATION PROJECT,
GROUND WATER INVESTIGATIONS FOCUS AREA
BOREHOLE LOG

BOREHOLE ID: R-22	TA/OU: TA-54	Page 7 of 21
DRILLING COMPANY: Stewart Bro./Dynatec	Start Date: 9/00	Finish Date: 11/00
DRILLING EQ/METHOD: CME-750/Foremost DR24	SAMPLING EQ/METHOD: Cuttings	
GROUND ELEVATION: 6650.5 ft DRILLER: Johnson/Thoren, Wilson, Woodward		TOTAL DEPTH = 1489 ft bgs GEOLOGY P.I.: Vaniman

Depth (ft)	Elevation (ft)	Core Run # (amt.-recov./amt. attemp.)	Core Run	Cuttings Collected	Geologic Characterization (Depth Interval)	Moisture/Matric Pot.	Lithology	Graphic Log	Lithologic Symbol
440	6210						CERROS DEL RIO BASALT: (437-467 ft) Basalt, similar to above with increasing oxidation with depth. Transition from tholeiitic to alkalic composition occurs within this interval (see Section 10.3.1 of this report).		
445	6205								
450	6200								
455	6195								
460	6190								
465	6185								
470	6180				Geologic (472-477 ft)		CERROS DEL RIO BASALT: (467-480 ft) Basalt, grayish black (N2) to black (N1), 10-15% olivine phenocrysts up to 1 mm.		
475	6175								Tb4
480	6170						CERROS DEL RIO BASALT: (480-548 ft) Basaltic cinder and scoria; possible thin lava flows. Abundant vitric cinder and oxidized scoria. Traces of quartzite and other metamorphic lithologies.		
485	6165								
490	6160								
495	6155								
500	6150								
505	6145				Geologic (507-512 ft)				
510	6140								
515	6135								
520	6130								
525	6125								

LOS ALAMOS NATIONAL LABORATORY
ENVIRONMENTAL RESTORATION PROJECT,
GROUND WATER INVESTIGATIONS FOCUS AREA
BOREHOLE LOG

BOREHOLE ID: R-22	TA/OU: TA-54	Page 8 of 21
DRILLING COMPANY: Stewart Bro./Dynatec	Start Date: 9/00	Finish Date: 11/00
DRILLING EQ/METHOD: CME-750/Foremost DR24		SAMPLING EQ/METHOD: Cuttings
GROUND ELEVATION: 6650.5 ft		TOTAL DEPTH = 1489 ft bgs
DRILLER: Johnson/Thoren, Wilson, Woodward		GEOLOGY P.I.: Vaniman

Depth (ft)	Elevation (ft)	Core Run # (amt.-recov./amt. attemp.)	Core Run	Cuttings Collected	Geologic Characterization (Depth Interval)	Moisture/Matric Pot.	Lithology	Graphic Log	Lithologic Symbol
530	6120								
535	6115								
540	6110								
545	6105				Geologic (543-548 ft)				
550	6100						CERROS DEL RIO BASALT: (548-580 ft) Basalt, med gray (N5), aphanitic, 10-15% phenocrysts, green olivine up to 1 mm, brown pyroxene, plagioclase. Dacite fragments also present; possible lavas plus basaltic sediments.		
555	6095								
560	6090								
565	6085								Tb4
570	6080								
575	6075								
580	6070						CERROS DEL RIO BASALT: (580-600 ft) Basalt-rich sediments, silty/sandy gravel (GM), basalt pebbles, yellowish gray (5Y7/2), brown clay. Cerros del Rio basaltic sediments and soil horizon from 580 to 600 feet.		
585	6065								
590	6060								
595	6055								
600	6050				Geologic (598-603 ft)		CERROS DEL RIO DACITE: (600-663 ft) Dacite, >5% phenocrysts up to 2 mm of plagioclase, olivine, pyroxene.		
605	6045								
610	6040								
615	6035								

LOS ALAMOS NATIONAL LABORATORY
ENVIRONMENTAL RESTORATION PROJECT,
GROUND WATER INVESTIGATIONS FOCUS AREA
BOREHOLE LOG

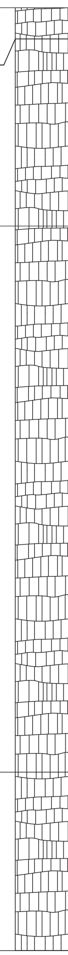
BOREHOLE ID: R-22	TA/OU: TA-54	Page 9 of 21
DRILLING COMPANY: Stewart Bro./Dynatec	Start Date: 9/00	Finish Date: 11/00
DRILLING EQ/METHOD: CME-750/Foremost DR24		SAMPLING EQ/METHOD: Cuttings
GROUND ELEVATION: 6650.5 ft		TOTAL DEPTH = 1489 ft bgs
DRILLER: Johnson/Thoren, Wilson, Woodward		GEOLOGY P.I.: Vaniman

Depth (ft)	Elevation (ft)	Core Run # (amt.-recov./amt. attemp.)	Core Run	Cuttings Collected	Geologic Characterization (Depth Interval)	Moisture/Matric Pot.	Lithology	Graphic Log	Lithologic Symbol
620	6030						CERROS DEL RIO DACITE: (600-663 ft) Dacite, >5% phenocrysts up to 2 mm of plagioclase, olivine, pyroxene.		
625	6025								
630	6020				Geologic (628-633 ft)				
635	6015								
640	6010								
645	6005								
650	6000								
655	5995								
660	5990								Tb4
665	5985						CERROS DEL RIO BASALT: (663-700 ft) Basalt, dark gray, aphanitic, 5-10% phenocrysts of olivine, pyroxene.		
670	5980								
675	5975								
680	5970								
685	5965				Geologic (683-688 ft)				
690	5960								
695	5955								
700	5950						CERROS DEL RIO BASALT: (700-710 ft) Mixed dacitic and basaltic lithologies; may represent very immature sediments.		
705	5945				Geologic (703-708 ft)				

LOS ALAMOS NATIONAL LABORATORY
ENVIRONMENTAL RESTORATION PROJECT,
GROUND WATER INVESTIGATIONS FOCUS AREA
BOREHOLE LOG

BOREHOLE ID: R-22	TA/OU: TA-54	Page 10 of 21
DRILLING COMPANY: Stewart Bro./Dynatec	Start Date: 9/00	Finish Date: 11/00
DRILLING EQ/METHOD: CME-750/Foremost DR24		SAMPLING EQ/METHOD: Cuttings
GROUND ELEVATION: 6650.5 ft		TOTAL DEPTH = 1489 ft bgs
DRILLER: Johnson/Thoren, Wilson, Woodward		GEOLOGY P.I.: Vaniman

Depth (ft)	Elevation (ft)	Core Run # (amt.-recov./amt. attemp.)	Core Run	Cuttings Collected	Geologic Characterization (Depth Interval)	Moisture/Matric Pot.	Lithology	Graphic Log	Lithologic Symbol
710	5940						CERROS DEL RIO BASALT: (700-710 ft) Mixed dacitic and basaltic sediments.		
715	5935						CERROS DEL RIO BASALT: (710-728 ft) Basalt, dark gray, aphanitic, 5-10% phenocrysts of olivine, pyroxene.		
720	5930								
725	5925				Geologic (723-728 ft)				
730	5920						CERROS DEL RIO BASALT: (728-780 ft) Dacite, gray (N5), pyroxene porphyritic.		
735	5915								
740	5910								
745	5905								
750	5900								Tb4
755	5895								
760	5890								
765	5885								
770	5880				Geologic (768-773 ft)				
775	5875								
780	5870						CERROS DEL RIO BASALT: (780-893 ft) Basalt, dark gray (N3), massive, minor vesicles to 1 mm, some red-yellow oxidation, minor olivine (?), and felsic phenocrysts/xenocrysts, minor medium light gray (N6) variety.		
785	5865								
790	5860								
795	5855				Geologic (793-798 ft)				



LOS ALAMOS NATIONAL LABORATORY
ENVIRONMENTAL RESTORATION PROJECT,
GROUND WATER INVESTIGATIONS FOCUS AREA
BOREHOLE LOG

BOREHOLE ID: R-22	TA/OU: TA-54	Page 11 of 21
DRILLING COMPANY: Stewart Bro./Dynatec	Start Date: 9/00	Finish Date: 11/00
DRILLING EQ/METHOD: CME-750/Foremost DR24		SAMPLING EQ/METHOD: Cuttings
GROUND ELEVATION: 6650.5 ft		TOTAL DEPTH = 1489 ft bgs
DRILLER: Johnson/Thoren, Wilson, Woodward		GEOLOGY P.I.: Vaniman

Depth (ft)	Elevation (ft)	Core Run # (amt.-recov./amt. attemp.)	Core Run	Cuttings Collected	Geologic Characterization (Depth Interval)	Moisture/Matric Pot.	Lithology	Graphic Log	Lithologic Symbol
800	5850						CERROS DEL RIO BASALT: (780-893 ft) Basalt, dark gray (N3), massive, minor vesicles to 1 mm, some red-yellow oxidation, minor olivine (?), and felsic phenocrysts/xenocrysts, minor medium light gray (N6) variety.		
805	5845								
810	5840								
815	5835								
820	5830								
825	5825								
830	5820								
835	5815								
840	5810								
845	5805								
850	5800								Tb4
855	5795								
860	5790								
865	5785								
870	5780								
875	5775								
880	5770								
885	5765								

LOS ALAMOS NATIONAL LABORATORY
ENVIRONMENTAL RESTORATION PROJECT,
GROUND WATER INVESTIGATIONS FOCUS AREA
BOREHOLE LOG

BOREHOLE ID: R-22	TA/OU: TA-54	Page 12 of 21
DRILLING COMPANY: Stewart Bro./Dynatec	Start Date: 9/00	Finish Date: 11/00
DRILLING EQ/METHOD: CME-750/Foremost DR24		SAMPLING EQ/METHOD: Cuttings
GROUND ELEVATION: 6650.5 ft		TOTAL DEPTH = 1489 ft bgs
DRILLER: Johnson/Thoren, Wilson, Woodward		GEOLOGY P.I.: Vaniman

Depth (ft)	Elevation (ft)	Core Run # (amt.-recov./amt. attemp.)	Core Run	Cuttings Collected	Geologic Characterization (Depth Interval)	Moisture/Matric Pot.	Lithology	Graphic Log	Lithologic Symbol
890	5760						CERROS DEL RIO BASALT: (780-893 ft) Basalt, dark gray (N3), massive, minor vesicles to 1 mm, some red-yellow oxidation, minor olivine (?), and felsic phenocrysts/xenocrysts, minor medium light gray (N6) andesite(?).		
895	5755								
900	5750						CERROS DEL RIO BASALT: (893-903 ft) No sample recovery.		
905	5745				Geologic (903-908 ft)		CERROS DEL RIO BASALT: (903-908 ft) Basalt, mafic to intermediate volcanic rock, med. to dk. gray (N3), porphyritic w/ aphanitic groundmass, plagioclase and pyroxene phenocrysts <5%, resorbed; massive structure w/rare small vesicles, local fractures exhibit Fe/Mn oxides.		
910	5740						CERROS DEL RIO BASALT: (908-913 ft) Basalt, med. to dk. gray (N3), porphyritic w/ aphanitic groundmass, local fractures w/ Fe/Mn oxides coating, single quartz grain (xenocryst) noted.		
915	5735								
920	5730						CERROS DEL RIO BASALT: (913-928 ft) Basalt, dark gray (N3), massive, porphyritic w/ aphanitic groundmass, phenocrysts of plagioclase and pyroxene <5% by volume, local Fe/Mn oxides on minor fractures.		Tb4
925	5725								
930	5720						CERROS DEL RIO BASALT: (928-933 ft) Basalt, massive (non-vesicular), porphyritic w/ aphanitic groundmass; pyroxene and plagioclase 3-5% by volume.		
935	5715						CERROS DEL RIO BASALT: (933-943 ft) Basalt, dark gray (N3), massive, porphyritic w/ aphanitic groundmass, phenocrysts of plagioclase and pyroxene <5% by volume.		
940	5710								
945	5705						CERROS DEL RIO BASALT: (943-948 ft) Basalt, massive w/ rare vesicles, (N4), rare silica-filled spherical vesicles; phenocrysts of feldspar and pyroxene <5% by volume.		
950	5700						CERROS DEL RIO BASALT: (948-953 ft) Basalt, massive, rare quartz xenocrysts (?).		
955	5695						CERROS DEL RIO BASALT: (953-958 ft) Basalt, aphyric to weakly porphyritic, massive.		

LOS ALAMOS NATIONAL LABORATORY
ENVIRONMENTAL RESTORATION PROJECT,
GROUND WATER INVESTIGATIONS FOCUS AREA
BOREHOLE LOG

BOREHOLE ID: R-22	TA/OU: TA-54	Page 13 of 21
DRILLING COMPANY: Stewart Bro./Dynatec	Start Date: 9/00	Finish Date: 11/00
DRILLING EQ/METHOD: CME-750/Foremost DR24		SAMPLING EQ/METHOD: Cuttings
GROUND ELEVATION: 6650.5 ft		TOTAL DEPTH = 1489 ft bgs
DRILLER: Johnson/Thoren, Wilson, Woodward		GEOLOGY P.I.: Vaniman

Depth (ft)	Elevation (ft)	Core Run # (amt.-recov./amt. attemp.)	Core Run	Cuttings Collected	Geologic Characterization (Depth Interval)	Moisture/Matric Pot.	Lithology	Graphic Log	Lithologic Symbol
960	5690						CERROS DEL RIO BASALT: (958-963 ft) Basalt, dark gray, massive, porphyritic w/ aphanitic groundmass; phenocrysts of feldspar, pyroxene, and olivine (?) <5% by volume, Fe/Mn oxides coating fractures.		
965	5685				Geologic (963-968 ft)		CERROS DEL RIO BASALT: (963-968 ft) Basalt, dark gray, mafic igneous rock, aphanitic, aphyric to weakly porphyritic, phenocrysts of plagioclase and ferromags, structure massive, non-vesicular.		
970	5680						CERROS DEL RIO BASALT: (968-970 ft) No sample recovery.		
975	5675						CERROS DEL RIO BASALT: (970-973 ft) Basalt, aphanitic, dk. gray (N3), aphyric, massive; local fracture surfaces show oxidation +/- silica coating.		
980	5670						CERROS DEL RIO BASALT: (973-978 ft) Basalt, med. gray (N4), aphanitic, aphryic to weakly porphyritic, rare vesicles.		
985	5665						CERROS DEL RIO BASALT: (978-983 ft) Basalt, similar to above, rare vesicles w/ local amygdaloidal silica (or quartz grains as xenocrysts).		Tb4
990	5660						CERROS DEL RIO BASALT: (983-988 ft) Basalt, massive, aphanitic, rare small vesicles.		
995	5655						CERROS DEL RIO BASALT: (988-998 ft) Basalt, dk. gray (N3), massive, weakly porphyritic w/ aphanitic groundmass, phenocrysts of feldspar, pyroxene, and olivine 1-3% by volume.		
1000	5650						CERROS DEL RIO BASALT: (998-1003 ft) Basalt, dk. gray (N3), massive, porphyritic w/ aphanitic groundmass, phenocrysts of feldspar, pyroxene, and olivine 1-3%.		
1005	5645						CERROS DEL RIO BASALT: (1003-1008 ft) Basalt, dk. gray (N3), massive, rare vesicles, weakly porphritic, phenocrysts of feldspar, pyroxene, and olivine are <5% by volume, rare quartz xenocrysts.		
1010	5640						CERROS DEL RIO BASALT: (1008-1013 ft) Basalt, dk. gray (N3), massive, aphyric to weakly porphyritic w/ aphantic groundmass; rare spherical amygdules filling small vesicles.		
1015	5635						CERROS DEL RIO BASALT: (1013-1018 ft) Basalt, dk. gray (N3), massive, aphyric to weakly porphyritic.		

LOS ALAMOS NATIONAL LABORATORY
ENVIRONMENTAL RESTORATION PROJECT,
GROUND WATER INVESTIGATIONS FOCUS AREA
BOREHOLE LOG

BOREHOLE ID: R-22	TA/OU: TA-54	Page 14 of 21
DRILLING COMPANY: Stewart Bro./Dynatec	Start Date: 9/00	Finish Date: 11/00
DRILLING EQ/METHOD: CME-750/Foremost DR24		SAMPLING EQ/METHOD: Cuttings
GROUND ELEVATION: 6650.5 ft		TOTAL DEPTH = 1489 ft bgs
DRILLER: Johnson/Thoren, Wilson, Woodward		GEOLOGY P.I.: Vaniman

Depth (ft)	Elevation (ft)	Core Run # (amt.-recov./amt. attemp.)	Core Run	Cuttings Collected	Geologic Characterization (Depth Interval)	Moisture/Matric Pot.	Lithology	Graphic Log	Lithologic Symbol
1020	5630						CERROS DEL RIO BASALT: (1018-1023 ft) Basalt, dk. gray (N3), massive, aphyric to weakly porphyritic. Local Fe/Mn oxides on fractures.		
1025	5625						CERROS DEL RIO BASALT: (1023-1028 ft) Basalt, dk. gray (N3), massive, porphyritic w/ aphanitic groundmass, <5% phenocrysts of feldspar, pyroxene, and olivine; strong Fe/Mn oxides development on fractures.		
1030	5620						CERROS DEL RIO BASALT: (1028-1033 ft) Basalt, dk. gray (N3), massive, porphyritic w/ aphanitic groundmass, phenocrysts of feldspar and pyroxene <5%, olivine possibly present, abundant Fe/Mn oxides on fracture surfaces.		
1035	5615						CERROS DEL RIO BASALT: (1033-1038 ft) Basalt, similar to above but including scoria; strong Fe/Mn oxides coating abundant fracture surfaces. Note: minor amt. of flesic volcanic rock present, plus black vitrophyre.		
1040	5610						CERROS DEL RIO BASALT: (1038-1043 ft) Basalt; dominantly pophyritic scoria; strong Fe/Mn oxides coating abundant fractures; 20% of particles may represent diverse rock types, partly andesite to dactite, with vitrophyre(?).		Tb4
1045	5605						CERROS DEL RIO BASALT: (1043-1048 ft) Basalt, 80-85% basalt particles, abundant fracture surfaces coated w/ Fe/Mn oxides, massive, weakly porphyritic, 15-20% med. gray porphyritic lithology w/10% phenocrysts of feldspar, pyroxene (?), and distinctive black vitrophyre; possibly scoria-bearing sediments.		
1050	5600						CERROS DEL RIO BASALT: (1048-1053 ft) Dominantly basalt, but including a variety of volcanic rocks with scoria, including lt. gray coarse-grained feldspar-porphyritic vesicular basalt; oxidized fracture surfaces.		
1055	5595				Geologic (1053-1058 ft)		CERROS DEL RIO BASALT: (1053-1058 ft) Basalt, 60% porphyritic basalt, plus diverse porphyritic rocks as described above, prominent black vitrophyre.		
1060	5590						CERROS DEL RIO BASALT: (1058-1063 ft) Basalt, dominantly fragments and scoria, commonly w/ Fe/Mn oxides on fractures; 20-30% other diverse volcanic rocks, including lt. gray porphyritic, hornblende(?) porphyritic, and vitrophyre.		

LOS ALAMOS NATIONAL LABORATORY
ENVIRONMENTAL RESTORATION PROJECT,
GROUND WATER INVESTIGATIONS FOCUS AREA
BOREHOLE LOG

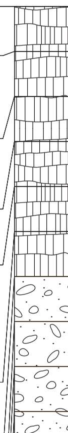
BOREHOLE ID: R-22	TA/OU: TA-54	Page 15 of 21
DRILLING COMPANY: Stewart Bro./Dynatec	Start Date: 9/00	Finish Date: 11/00
DRILLING EQ/METHOD: CME-750/Foremost DR24		SAMPLING EQ/METHOD: Cuttings
GROUND ELEVATION: 6650.5 ft		TOTAL DEPTH = 1489 ft bgs
DRILLER: Johnson/Thoren, Wilson, Woodward		GEOLOGY P.I.: Vaniman

Depth (ft)	Elevation (ft)	Core Run # (amt.-recov./amt. attemp.)	Core Run	Cuttings Collected	Geologic Characterization (Depth Interval)	Moisture/Matric Pot.	Lithology	Graphic Log	Lithologic Symbol
1065	5585						CERROS DEL RIO BASALT: (1063-1068 ft) Basalt, dk. gray (N3), 80% massive basalt clasts, aphyric to weakly porphyritic, Fe/Mn oxides on fractures common, 20% lt. gray porphyry, vitrophyre, other varieties.		
1070	5580								
1075	5575						CERROS DEL RIO BASALT: (1068-1073 ft) Basalt, dk. gray (N3), 85% basaltic clasts, weakly porphyritic to aphanitic, rare vesicles, 15% varied lithologies: lt. gray porphyritic variety, vesicular basalt, vitrophyre, etc.		
1080	5570								
1085	5565						CERROS DEL RIO BASALT: (1073-1078 ft) Basalt, dk. gray (N3), 85% massive to vesicular clasts, porphyritic, 40% varied textures, mostly lt. gray (N7) porphyritic, vitrophrye, vesicular basalt.		
1090	5560								
1095	5555						CERROS DEL RIO BASALT: (1078-1083 ft) Olivine basalt, phenocrysts (5-7% by volume) of olivine (1.5 mm) and feldspar; 2% other lithology with aphanitic ground-mass, dk. gray (N3), Fe/Mn oxides on local fractures.		
1100	5550								Tb4
1105	5545						CERROS DEL RIO BASALT: (1083-1088 ft) Basalt, dk. gray (N3), porphyritic w/ aphanitic groundmass, phenocrysts of olivine (1.5 mm), feldspar (2 mm), rare quartz xenocrysts, rare vesicles w/ or w/o anygdaloidal silica, Fe/Mn oxides coating fractures; 3% other textures.		
1110	5540								
1115	5535								
1120	5530						CERROS DEL RIO BASALT: (1088-1133 ft) No sample recovery.		
1125	5525								
1130	5520								
1135	5515						CERROS DEL RIO BASALT: (1133-1138 ft) Basalt, 80% clasts of weakly porphyritic basalt, masive to partly vesicular, phenocrysts of pyroxene and plagioclase <5% by volume, aphanitic groundmass, 20% pebble gravel, white to lt. gray, siliceous to intermediate volcanic rocks; >10 mesh fraction has rounded clasts, minor glass.		
1140	5510						CERROS DEL RIO BASALT: (1138-1143 ft) Basalt, dk. gray, porphyritic w/ aphanitic groundmass, phenocrysts of pyroxene and feldspar <5% by volume; massive, nonvesicular.		

LOS ALAMOS NATIONAL LABORATORY
ENVIRONMENTAL RESTORATION PROJECT,
GROUND WATER INVESTIGATIONS FOCUS AREA
BOREHOLE LOG

BOREHOLE ID: R-22	TA/OU: TA-54	Page 16 of 21
DRILLING COMPANY: Stewart Bro./Dynatec	Start Date: 9/00	Finish Date: 11/00
DRILLING EQ/METHOD: CME-750/Foremost DR24		SAMPLING EQ/METHOD: Cuttings
GROUND ELEVATION: 6650.5 ft DRILLER: Johnson/Thoren, Wilson, Woodward		TOTAL DEPTH = 1489 ft bgs GEOLOGY P.I.: Vaniman

Depth (ft)	Elevation (ft)	Core Run # (amt.-recov./amt. attemp.)	Core Run	Cuttings Collected	Geologic Characterization (Depth Interval)	Moisture/Matric Pot.	Lithology	Graphic Log	Lithologic Symbol
1145	5505						CERROS DEL RIO BASALT: (1143-1148 ft) Basalt, similar to above.		Tb4
1150	5500						CERROS DEL RIO BASALT: (1148-1153 ft) 90% basalt, dark gray, porphyritic, as above; 10% white siliceous variety, porphyritic; minor black vitrophyre.		
1155	5495						CERROS DEL RIO BASALT: (1153-1158 ft) Basalt, dk. gray, aphanitic groundmass, aphyric, locally oxidized, massive, nonvesicular.		
1160	5490						CERROS DEL RIO BASALT: (1158-1163 ft) Similar to above; strong oxidization on most particles.		
1165	5485				Geologic (1163-1168 ft)		CERROS DEL RIO BASALT: (1163-1168 ft) Basalt-rich sediments, 90% basalt, dk. gray, porphyritic w/ aphanitc groundmass, phenocrysts of pyroxene and feldspar, 10% white quartz-feldspar-biotite porphyritic, felsic volcanic clasts present as rounded pebbles.		Tb4 (sediments)
1170	5480						CERROS DEL RIO BASALT: (1168-1173 ft) Basalt-rich sediments - similar to above lithologies, 95% basalt clasts; 5% felsic volcanics pebbles.		
1175	5475						PUYE FORMATION: (1173-1178 ft) Sand (SP), reddish brown, fine- to very fine-grained, quartz and feldspar>>mica w/ abundant basalt/andesite; grains subrounded; minor felsic holocrystalline igneous rocks.		Tpf
1180	5470						PUYE FORMATION: (1178-1183 ft) No sample recovery.		
1185	5465						PUYE FORMATION: (1183-1188 ft) Clastic sediments, sand, reddish-brown silty, very fine-grained sand.		
1190	5460				Geologic (1188-1191 ft)		PUYE FORMATION: (1188-1191 ft) Volcaniclastic sediments, gravel w/ coarse sand, gravel subangular to subrounded; sand, rounded to subrounded, derived from quartz-bearing felsic volcanics. Note: gray coarsely-porphyritic (plagioclase-biotite phenocrysts); likely derived from Tschicoma Fm.		



LOS ALAMOS NATIONAL LABORATORY
ENVIRONMENTAL RESTORATION PROJECT,
GROUND WATER INVESTIGATIONS FOCUS AREA
BOREHOLE LOG

BOREHOLE ID: R-22 TA/OU: TA-54

DRILLING COMPANY: Stewart Bro./Dynatec Start Date: 9/00 Finish Date: 11/00

DRILLING EQ/METHOD: CME-750/Foremost DR24 SAMPLING EQ/METHOD: Cuttings

GROUND ELEVATION: 6650.5 ft TOTAL DEPTH = 1489 ft bgs

DRILLER: Johnson/Thoren, Wilson, Woodward GEOLOGY P.I.: Vaniman

Depth (ft)	Elevation (ft)
1195	5455
1200	5450
1205	5445
1210	5440
1215	5435
1220	5430
1225	5425
1230	5420
1235	5415
1240	5410
1245	5405
1250	5400
1255	5395
1260	5390
1265	5385

Column headings: Depth (ft) | Elevation (ft) | Core Run # (amt.-recov./amt. attemp.) | Core Run | Cuttings Collected | Geologic Characterization (Depth Interval) | Moisture/Matric Pot. | Lithology | Graphic Log | Lithologic Symbol

Lithology:

PUYE FORMATION: (1191-1237 ft) No sample recovery.

PUYE FORMATION: (1237-1258 ft) Volcaniclastic sediments, gravel w/ fine to v. coarse-grained sand, clasts of siliceous to mafic volcanics (intermediate volcanics predominant) and quartzite (5-10%), quartzite decreases in abundance with depth; gravel clasts are angular to subrounded; sands are quartz-bearing w/ siliceous to intermediate volcanics and trace amounts of mafic volcanics; sands are angular to subrounded; possible plutonic clasts.

PUYE FORMATION: (1258-1263 ft) Volcaniclastic sediments, sand with gravel, light gray (N6) fine sand to pebble gravels (max 1.5 cm diam), >95% gray to reddish-brown intermediate volcanic rocks (likely derived from Tschicoma Fm.), mostly hornblende dacite. <5% white to gray quartzite, >35 mesh well-rounded to subangular.

PUYE FORMATION: (1263-1268 ft) Sand with gravel, light gray (N6), fine-grained to v.f.g. sand w/ 10% pebbles (max 2 cm diam), 95% of clasts composed of intermediate to siliceous volcanic rock, gray porphyritic andesite, and white pumice, minor (1-5%) quartzite.

Lithologic Symbol: Tpf

LOS ALAMOS NATIONAL LABORATORY
ENVIRONMENTAL RESTORATION PROJECT,
GROUND WATER INVESTIGATIONS FOCUS AREA
BOREHOLE LOG

BOREHOLE ID: R-22	TA/OU: TA-54	Page 18 of 21
DRILLING COMPANY: Stewart Bro./Dynatec	Start Date: 9/00	Finish Date: 11/00
DRILLING EQ/METHOD: CME-750/Foremost DR24		SAMPLING EQ/METHOD: Cuttings
GROUND ELEVATION: 6650.5 ft		TOTAL DEPTH = 1489 ft bgs
DRILLER: Johnson/Thoren, Wilson, Woodward		GEOLOGY P.I.: Vaniman

Depth (ft)	Elevation (ft)	Core Run # (amt.-recov./amt. attemp.)	Core Run	Cuttings Collected	Geologic Characterization (Depth Interval)	Moisture/Matric Pot.	Lithology	Graphic Log	Lithologic Symbol
1270	5380						PUYE FORMATION: (1268-1273 ft) Volcaniclastic sediments, sand, moderate brown (10YR4/4) fine to very coarse sand w/ 5% pebbles (max 3 cm); >35 mesh size well rounded to subangular, consisting of 95% reddish to gray porphyritic intermediate volcanics, 5% white quartzite.		
1275	5375				Geologic (1273-1278 ft)				
1280	5370								
1285	5365						PUYE FORMATION: (1273-1278 ft) Volcaniclastic sediments, silty sand with gravel medium-brown (10YR4/2), very fine silty sand to pebble gravel (max 2.0 cm diam.); >10 fraction contains 90% rounded-subangular gray (N6) to red-brown (10YR3/4) coarsely porphyritic intermediate volcanics and 10% felsic to intermediate porphyritic volcanic rocks and minor quartzite.		
1290	5360								
1295	5355								
1300	5350						PUYE FORMATION: (1278-1288 ft) Volcaniclastic sediments, sand, medium brown (10YR4/2), medium to very coarse, minor small pebbles, >90% porphyritic intermediate volcanics, <10% quartzite, felsic volcanics, and vitrophyre.		Tpf
1305	5345								
1310	5340								
1315	5335						PUYE FORMATION: (1288-1323 ft) Clastic sediments, sandy gravel/gravelly sand; mostly intermediate to mafic volcanics, granitic and quartzite clasts up to 3 cm are angular to subrounded; coarse- to very coarse sand (subangular to subrounded) made up of 10-15% quartzite; volcanics decrease and granitic rocks increase in abundance with depth.		
1320	5330								
1325	5325				Geologic (1323-1328 ft)				
1330	5320						PUYE FORMATION: (1323-1333 ft) Clastic sediments, clayey sand to silty sand wilh gravel; 10-15% fines; remainder is very fine to very coarse sand and gravels (up to 2 cm); trace mafic volcanics(?); granitic gravels; gravels are angular to subrounded; sands are subangular to subrounded.		
1335	5315						PUYE FORMATION: (1333-1338 ft) Clastic sediments, gravel with sand, basalt-rich interval, 80% gray (N5) olivine basalt (porphyritic, nonvesicular and aphanitic vesicular), 20% gravel clasts made up of felsic volcanics, quartzite, and reddish porphyritic volcanic rocks.		

LOS ALAMOS NATIONAL LABORATORY
ENVIRONMENTAL RESTORATION PROJECT,
GROUND WATER INVESTIGATIONS FOCUS AREA
BOREHOLE LOG

BOREHOLE ID: R-22	TA/OU: TA-54	Page 19 of 21
DRILLING COMPANY: Stewart Bro./Dynatec	Start Date: 9/00	Finish Date: 11/00
DRILLING EQ/METHOD: CME-750/Foremost DR24		SAMPLING EQ/METHOD: Cuttings
GROUND ELEVATION: 6650.5 ft		TOTAL DEPTH = 1489 ft bgs
DRILLER: Johnson/Thoren, Wilson, Woodward		GEOLOGY P.I.: Vaniman

Depth (ft)	Elevation (ft)	Core Run # (amt.-recov./amt. attemp.)	Core Run	Cuttings Collected	Geologic Characterization (Depth Interval)	Moisture/Matric Pot.	Lithology	Graphic Log	Lithologic Symbol
1340	5310						SANTA FE GROUP BASALT: (1338-1343 ft) Basalt, gray (N5), 70% of clasts are of vesicular basalt, abundant phenocrysts (30%) plagioclase laths, olivine (brown iddingsite), up to 3 mm, euhedral. Also present is a variety that is more uniformly coarse-grained w/minor phenocrysts; 30% mixed porphyritic volcanic lithologies and traces of quartzite; interval is a Tpf/Tb2 transition.		
1345	5305				Geologic (1347-1352 ft)		SANTA FE GROUP BASALT: (1343-1345 ft) Dominantly coarse-grained porphyrtic basalt w/ 10% olivine phenocrysts.		
1350	5300						SANTA FE GROUP BASALT: (1345-1352 ft) Basalt, gray, coarse-grained, olivine porphyritic; minor intermediate volcanic clasts.		
1355	5295						SANTA FE GROUP BASALT: (1352-1357 ft) Olivine basalt, porphyritic, intergranular-textured groundmass of plagioclase and ferromagnesian minerals.		
1360	5290						SANTA FE GROUP BASALT: (1357-1367 ft) Basalt, porphyritic, dark gray (N3), 5% olivine, intergranular groundmass.		
1365	5285						SANTA FE GROUP BASALT: (1367-1377 ft) Basalt, dark gray (N3), porphyritic, 10% olivine phenocrysts, nonvesicular.		
1370	5280						SANTA FE GROUP BASALT: (1377-1382 ft) Basalt, gray, coarse-grained, porphyritic, 10% olivine phenocrysts.		
1375	5275						SANTA FE GROUP BASALT: (1382-1392 ft) Basalt, dk. gray (N3), porphyritic, intergranular groundmass w/ plagioclase and olivine; 10% clay that is moderate brown (5YR4/4) to light brown (5YR6/4) w/ laminae.		Tb2
1380	5270				Geologic (1377-1382 ft)		SANTA FE GROUP BASALT: (1392-1397 ft) Basalt, dk. gray (N3), coarse-grained, plagioclase, ferromagnesian and olivine phenocrysts, nonvesicular; 10% felsic volcanic lithologies.		
1385	5265						SANTA FE GROUP BASALT: (1397-1406 ft) Basalt, as above; 20% coarse sandstone, moderate reddish brown (10YR4/6), w/ lithic fragments up to 2 mm.		
1390	5260								
1395	5255				Geologic (1397-1402 ft)				
1400	5250								

LOS ALAMOS NATIONAL LABORATORY
ENVIRONMENTAL RESTORATION PROJECT,
GROUND WATER INVESTIGATIONS FOCUS AREA
BOREHOLE LOG

BOREHOLE ID: R-22	TA/OU: TA-54	Page 20 of 21
DRILLING COMPANY: Stewart Bro./Dynatec	Start Date: 9/00	Finish Date: 11/00
DRILLING EQ/METHOD: CME-750/Foremost DR24		SAMPLING EQ/METHOD: Cuttings
GROUND ELEVATION: 6650.5 ft		TOTAL DEPTH = 1489 ft bgs
DRILLER: Johnson/Thoren, Wilson, Woodward		GEOLOGY P.I.: Vaniman

Depth (ft)	Elevation (ft)	Core Run # (amt.-recov./amt. attemp.)	Core Run	Cuttings Collected	Geologic Characterization (Depth Interval)	Moisture/Matric Pot.	Lithology	Graphic Log	Lithologic Symbol
1405	5245								Tb2
1410	5240				Geologic (1412-1417 ft)		PUYE FORMATION: (1406-1467 ft) Clastic sediments, sandy gravel, pebble gravel up to 1.5 mm, subangular to subrounded, sand grains of quartz and feldspar w/ pebbles of volcanic lithologies.		
1415	5235								
1420	5230								
1425	5225								
1430	5220								
1435	5215								
1440	5210				Geologic (1442-1447 ft)				Tpf (?)
1445	5205				Geologic (1447-1452 ft)				
1450	5200				Geologic (1452-1457 ft)				
1455	5195								
1460	5190								
1465	5185								
1470	5180						PUYE FORMATION: (1467-1472 ft) Clastic sediments, sand, gray brown (10R 4/1) fine to coarse-grained sand; >10 mesh fraction contains arkosic sandstone with quartz, feldspar, and ferromagnesian silicates, pumice, basalt lithics.		
1475	5175						PUYE FORMATION: (1472-1477 ft) Clastic sediments, sand, medium brown (10YR4/4) fine- to medium-grained: >35 fraction mesh fraction contains quartz, feldspar, and biotite w/ 30% dark-colored lithics as subangular to very well-rounded grains.		

LOS ALAMOS NATIONAL LABORATORY
ENVIRONMENTAL RESTORATION PROJECT,
GROUND WATER INVESTIGATIONS FOCUS AREA
BOREHOLE LOG

BOREHOLE ID: R-22	TA/OU: TA-54	Page 21 of 21
DRILLING COMPANY: Stewart Bro./Dynatec	Start Date: 9/00	Finish Date: 11/00
DRILLING EQ/METHOD: CME-750/Foremost DR24	SAMPLING EQ/METHOD: Cuttings	
GROUND ELEVATION: 6650.5 ft DRILLER: Johnson/Thoren, Wilson, Woodward		TOTAL DEPTH = 1489 ft bgs GEOLOGY P.I.: Vaniman

Depth (ft)	Elevation (ft)	Core Run # (amt.-recov./amt. attemp.)	Core Run	Cuttings Collected	Geologic Characterization (Depth Interval)	Moisture/Matric Pot.	Lithology	Graphic Log	Lithologic Symbol
1480	5170						PUYE FORMATION: (1477-1482 ft) Clastic sediments, gravelly sand, varicolored v. fine to v. coarse sand w/30-40% pebbles (2-3 cm); pebbles could represent a discrete pebbly lens; >10 mesh fraction contains 30-40% white to orange-brown oxidized biotite pumice; 50% vitrophyric lithologies; felsic to intermediate volcanic rocks; and <10 % quartzite.		Tpf (?)
1485	5165				Geologic (1482-1487 ft)		PUYE FORMATION: (1482-1487 ft) Clastic sediments, sand, varicolored, medium to very coarse sand, >10 mesh fraction contains subangular to subrounded granules and broken pebbles, 10% orange-brown medium grained sandstone w/ mafic grains, 90% basalt; silicic to intermediate porphyritic volcanic rocks, glassy porphyritic volcanic rocks; and pumice.		
1490	5160						PUYE FORMATION: (1487-1489 ft) No sample recovery; total drill depth (TD) at 1489 ft bgs.		
1495	5155								
1500									

Appendix D

Westbay's^{TM} MP55 Well Components Installed in R-22

Summary MP Casing Log

Company: LANL
Well: R22
Site:
Project: Hydrogeology Characterization

Job No: WB777
Author: DL

Well Information

Reference Datum: ground level
Elevation of Datum: 0.00 ft.
MP Casing Top: 0.00 ft.
MP Casing Length: 1469.95 ft.
Depth Adjusted For:
Field De-Stressing
Well Description:
Plastic MP55 System
Other References:
4.5 in ID SS casing+screens: LANL10/20
Backfill TBD 11 Nov 00
MagneticCollars 2.5 ft below port top

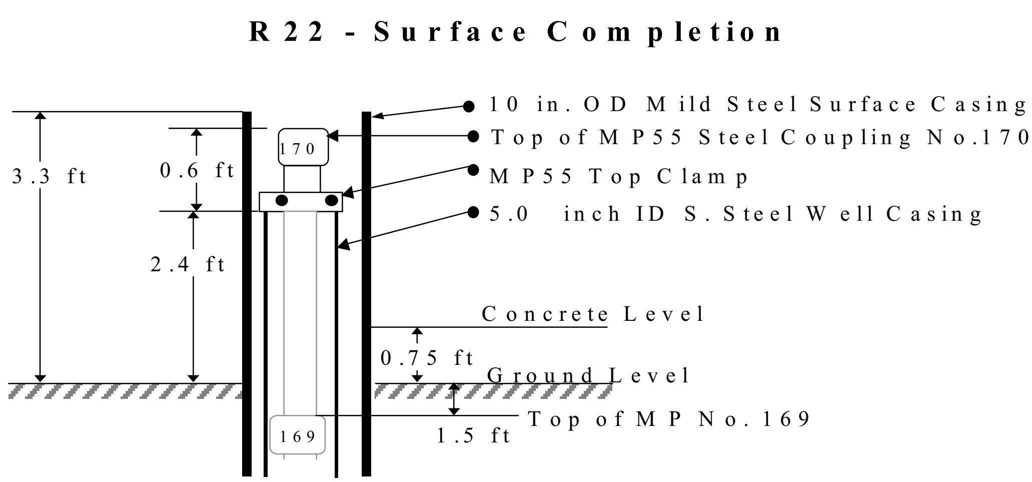
Borehole Depth: 1489.00 ft.
Borehole Inclination: vertical
Borehole Diameter: 12.00 in.

File Information

File Name: 777_R22.WWD
Report Date: Mon Dec 11 21:38:48 2000

File Date: Dec 10 17:38:04 2000

Sketch of Wellhead Completion

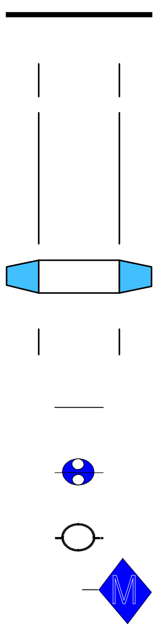


Summary MP Casing Log
LANL

Job No: WB777
Well: R22

Legend

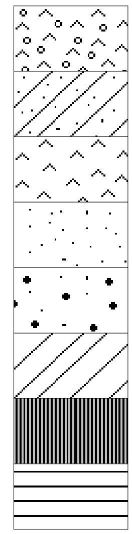
(Qty) MP Components



- (2) 0603 - MP55 End Plug
- (20) 0601M15 - MP55 Casing, PVC, 1.5m
- (130) 0601M30 - MP55 Casing, PVC, 3.0m
- (14) 0612M15 - MP55 Packer with stiffeners
- (6) 0601M10 - MP55 Casing, PVC, 1.0m
- (146) 0602 - MP55 Regular Coupling
- (21) 0605 - MP55 Measurement Port
- (5) 0607 - MP55 Hydraulic Pumping Port
- (9) 0608 - MP55 Magnetic Location Collar

Geology

Backfill/Casing

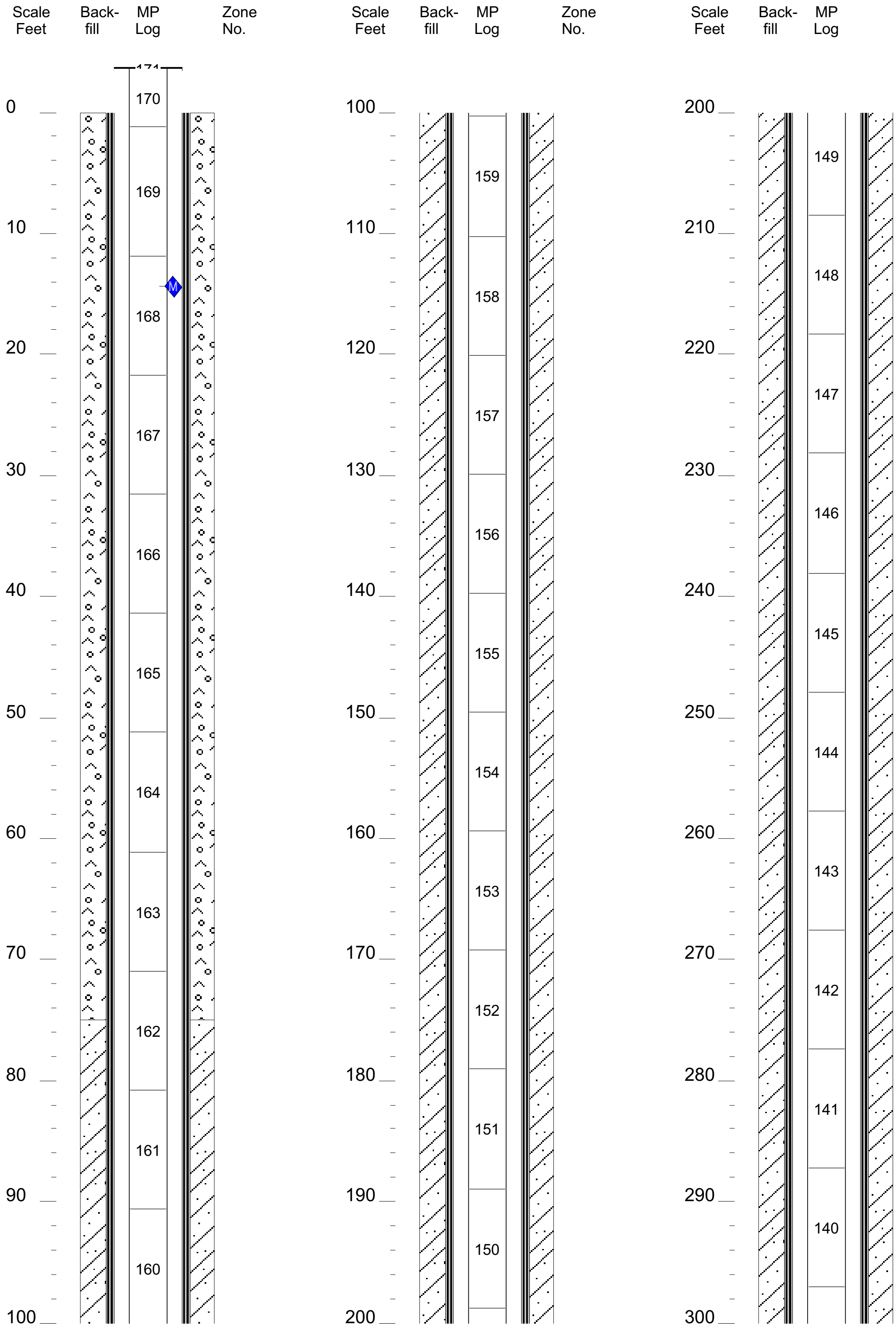


- Concrete
- Bentonite, Sand
- Grout
- Sand Fine
- Sand Coarse
- Bentonite
- Stainless Steel
- Well Screen

(c) Westbay Instruments Inc. 1998 Mon Dec 11 21:38:49 2000 Page: 2

Summary MP Casing Log
LANL

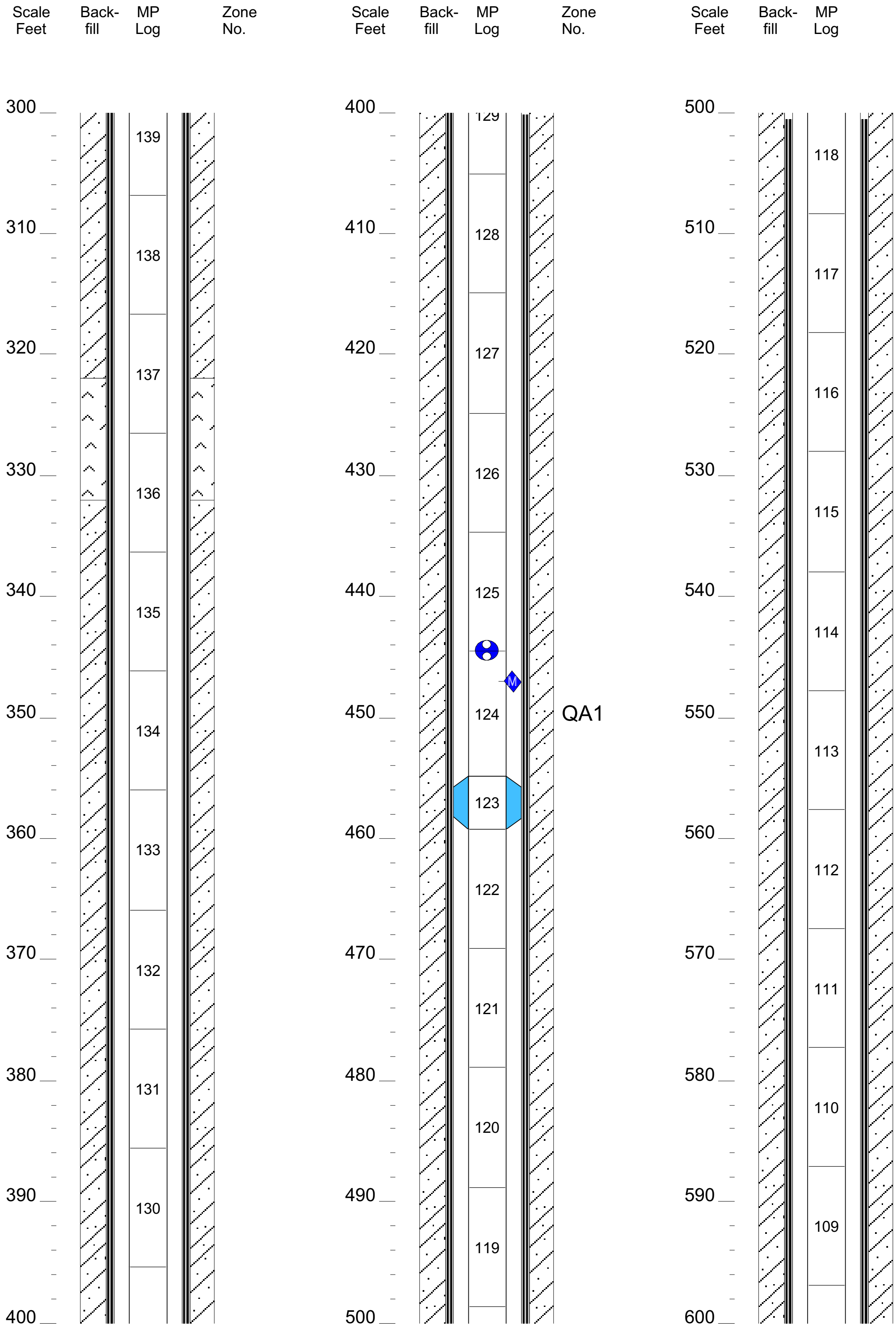
Job No: WB777
Well: R22



(c) Westbay Instruments Inc. 1998 Mon Dec 11 21:38:52 2000 Page: 3

Summary MP Casing Log
LANL

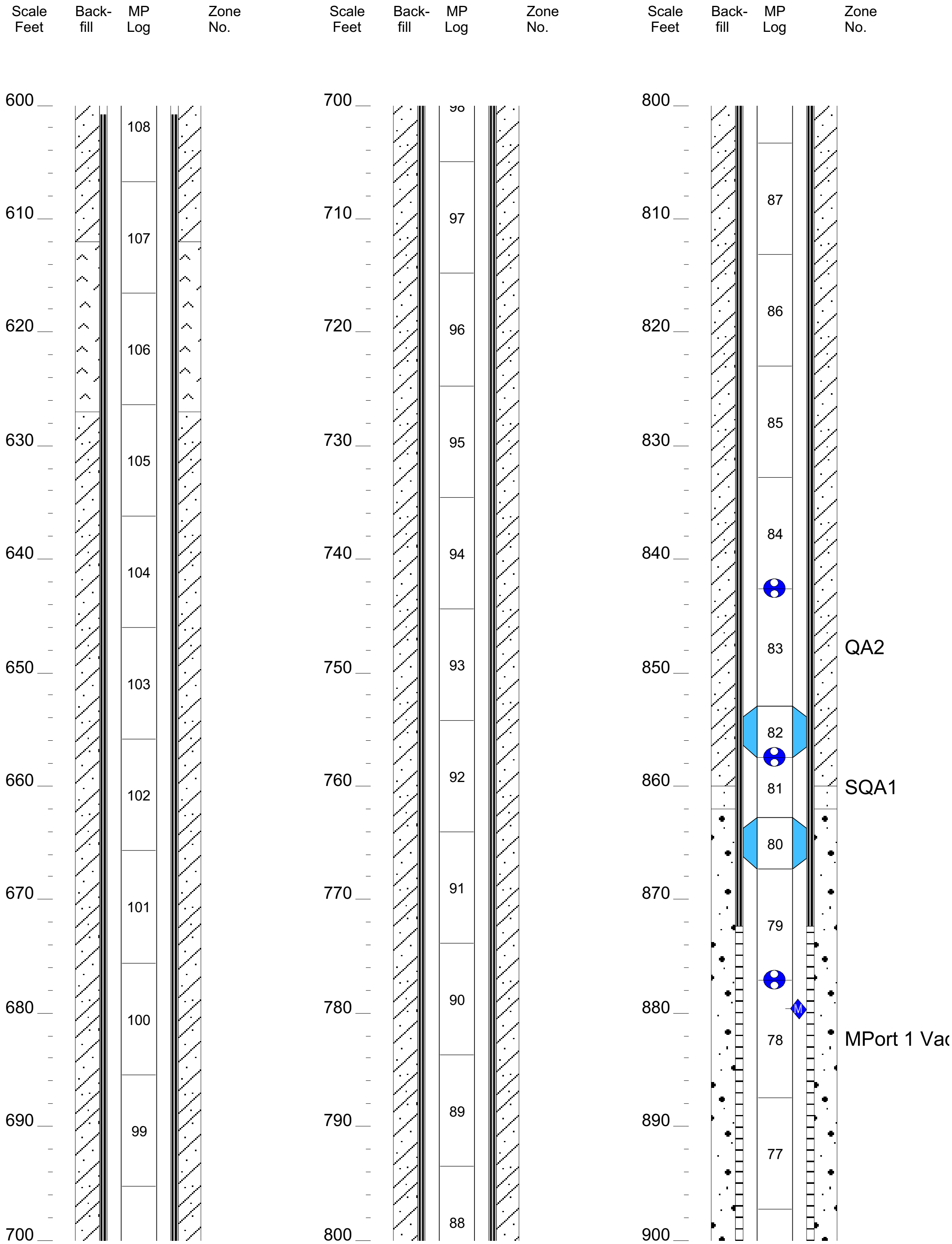
Job No: WB777
Well: R22



(c) Westbay Instruments Inc. 1998 Mon Dec 11 21:38:58 2000 Page: 4

Summary MP Casing Log
LANL

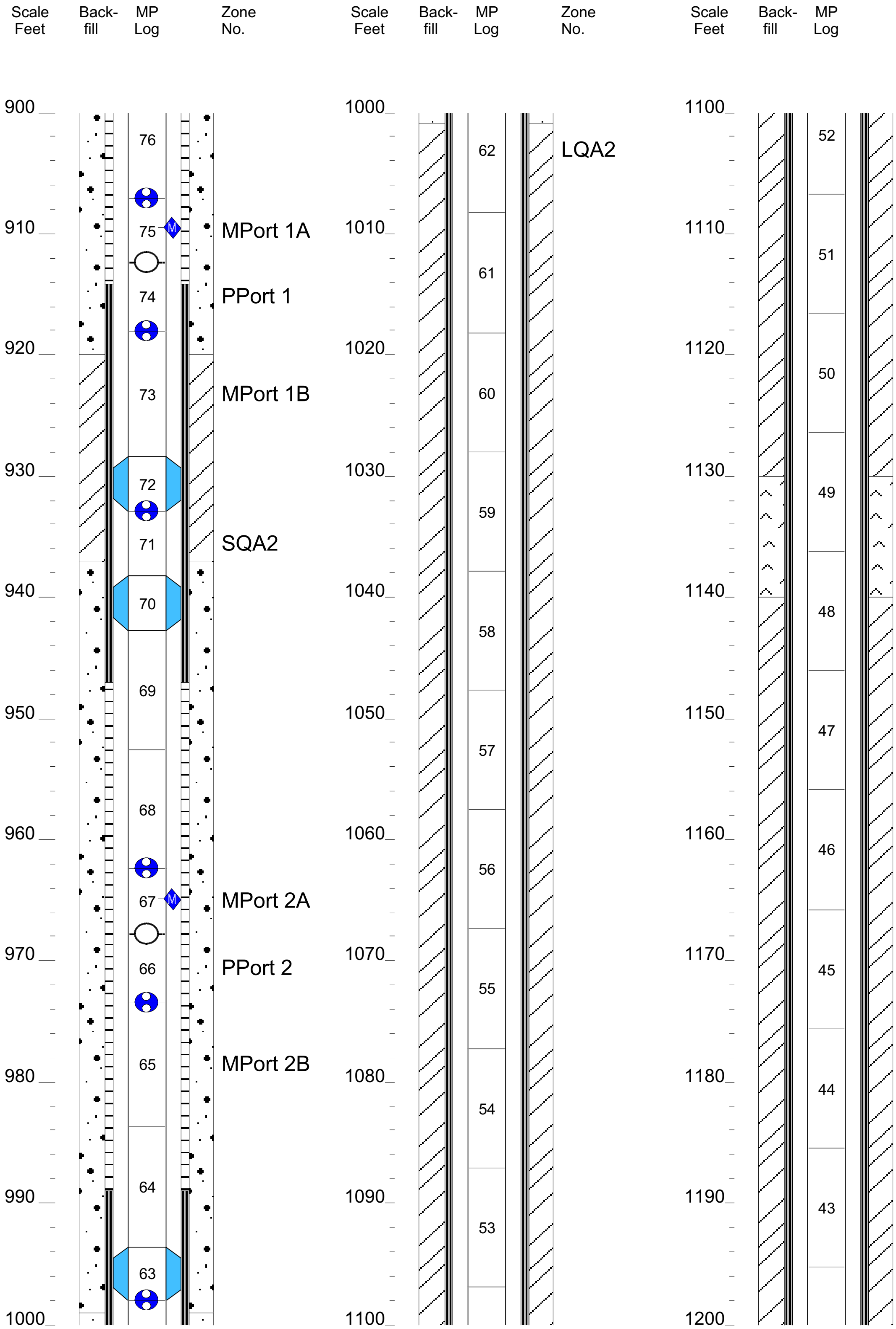
Job No: WB777
Well: R22



(c) Westbay Instruments Inc. 1998 Mon Dec 11 21:39:05 2000 Page: 5

Summary MP Casing Log
LANL

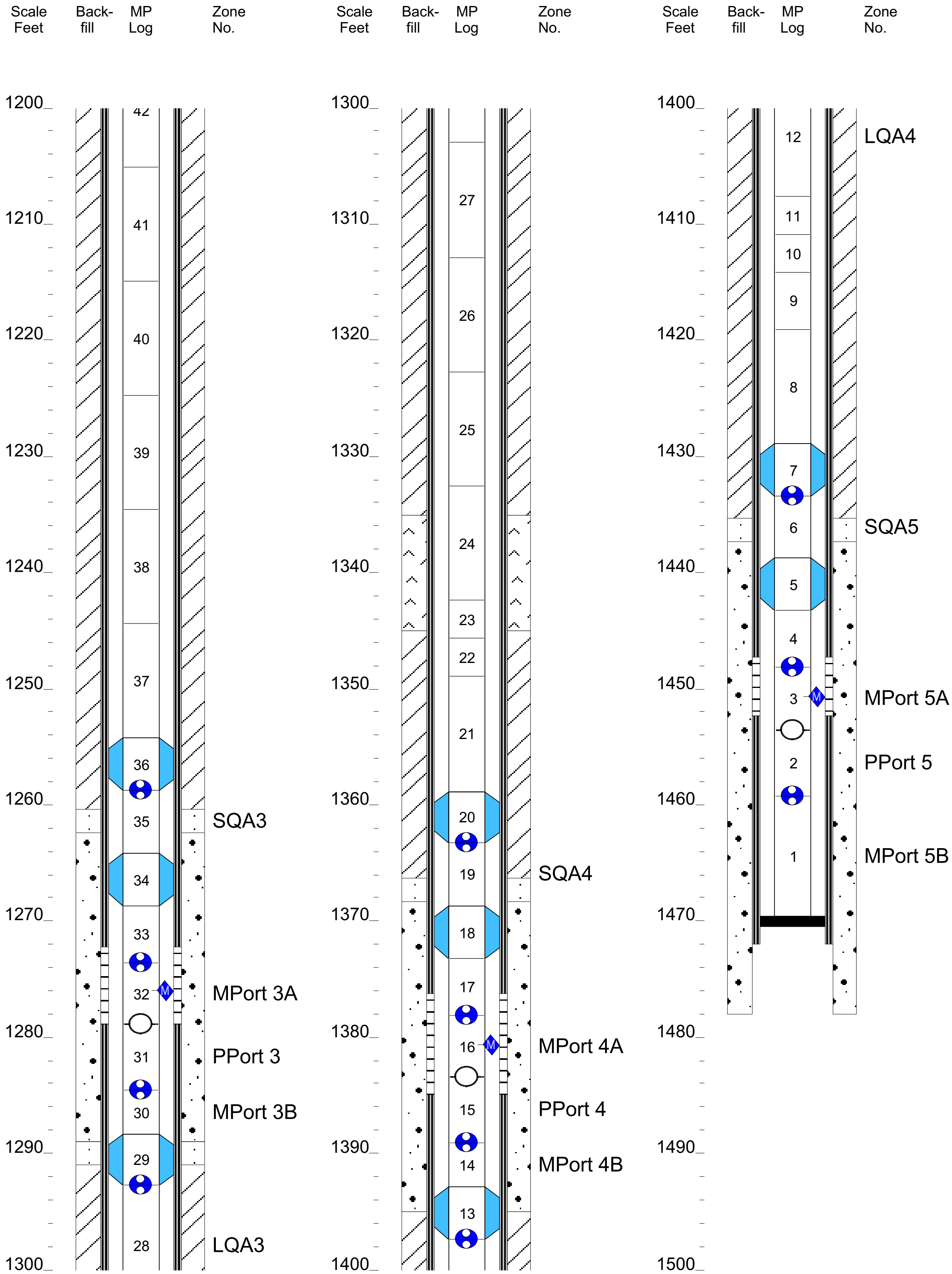
Job No: WB777
Well: R22



(c) Westbay Instruments Inc. 1998 Mon Dec 11 21:41:42 2000 Page: 6

Summary MP Casing Log
LANL

Job No: WB777
Well: R22



(c) Westbay Instruments Inc. 1998 Mon Dec 11 21:41:49 2000 Page: 7

Appendix E

Descriptions of Geologic Samples

APPENDIX E DESCRIPTION OF GEOLOGIC SAMPLES

R-22 217-222 Hand-picked fragments	This polished thin section contains an olivine-porphyritic basalt with ~0.45-mm olivine phenocrysts in ~4% abundance. Bodies of subophitic pyroxene are abundant; some are up to 1.5 mm in size, but most are ~0.5 mm. Olivine phenocrysts have moderate abundances of spinel inclusions.
R-22 377-382 Hand-picked fragments	This polished thin section contains an olivine-porphyritic basalt with ~3% olivine phenocrysts that are up to 0.8 mm in size. Bodies of subophitic pyroxene are abundant; most are ~0.4 mm in size. Olivine phenocrysts have abundant spinel inclusions.
R-22 427-432 Hand-picked fragments	This polished thin section contains an olivine-porphyritic basalt with ~3% olivine phenocrysts that are up to 2 mm in size, though most are ~0.5 mm. Bodies of subophitic pyroxene are abundant; most are ~0.3 mm in size. Olivine phenocrysts have abundant spinel inclusions.
R-22 472-477 Hand-picked fragments	This polished thin section contains two hand-picked subsamples: (1) an olivine-porphyritic basalt lava with ~10% olivine phenocrysts up to ~1 mm in size with few spinel inclusions, and (2) a related olivine-rich basaltic cinder that also contains ~10% olivine phenocrysts to 1 mm in size, with few spinel inclusions.
R-22 507-512 2- to 4-mm size fraction	This polished thin section contains vitric basaltic cinder with very coarse (up to 2 mm) euhedral olivine having few spinel inclusions. Plagioclase laths are few and small (0.3 mm).
R-22 543-548 Hand-picked fragments	This polished thin section contains a varied suite of lavas, including (1) coarse intergranular dacitic lava with clinopyroxene and orthopyroxene phenocrysts, (2) dacitic pumice with clinopyroxene and orthopyroxene phenocrysts, (3) dacitic lava with amphibole and clinopyroxene phenocrysts, and (4) a porphyritic olivine basalt with ~10% olivine phenocrysts.
R-22 598-603 Hand-picked fragments	This polished thin section contains two hand-picked subsamples: (1) calcrete rims from basaltic clasts; calcrete is ooidal and forms thick layered masses (>2 mm) cementing detrital silt composed of quartz and plagioclase with rarer amphibole and biotite, and (2) a dacitic lava with clinopyroxene and orthopyroxene phenocrysts (both up to 0.3 mm in size), larger phenocrysts of sieved and resorbed plagioclase (up to 0.8 mm), rare 0.3 mm reacted phenocrysts of amphibole with yellow-orange pleochroism, and large rounded quartz xenocrysts (up to 2 mm) with fine-grained pyroxene reaction rims.
R-22 628-633 Hand-picked fragments	This polished thin section contains fragments of a felsic lava with clinopyroxene and orthopyroxene phenocrysts (clinopyroxene up to 0.5 mm and euhedral, with “hourglass” sector zoning; orthopyroxene less abundant, euhedral, elongate, and up to 0.25 mm), phenocrysts of reacted or sieved plagioclase (two populations) up to 0.8 mm, and quartz xenocrysts (up to 0.2 mm), with flow-oriented plagioclase laths in a vitric matrix.
R-22 683-688 Hand-picked fragments	This polished thin section contains yellow to black glassy basalt cinder having euhedral olivine phenocrysts up to 0.6 mm and subophitic clinopyroxene. Some of the ophitic pyroxenes have overgrowths of smaller, tabular euhedral clinopyroxene crystals.
R-22 703-708 Hand-picked fragments	This polished thin section contains two hand-picked subsamples: (1) an intersertal olivine, clinopyroxene-porphyritic basalt with olivine phenocrysts up to 0.5 mm in size and clinopyroxene grains up to 0.3 mm, and (2) a pilotaxitic dacitic lava with euhedral clinopyroxene (to 0.4 mm) and orthopyroxene (to 0.8 mm) phenocrysts, reacted and sieved plagioclase phenocrysts (two populations) to 0.6 mm in size, and rounded quartz grains up to 1.5 mm with fine-grained pyroxene reaction rims.

R-22 723-728 Hand-picked fragments	This polished thin section contains an intersertal olivine-porphyritic basalt with euhedral olivine phenocrysts up to 1.5 mm in size, grading down to groundmass sizes of ~0.1 mm. Clinopyroxene is subophitic and ~0.2 mm in size. Edges of some clasts contain abundant yellow-orange clay, penetrating up to ~2 mm into some clasts; this clay was avoided in those clasts selected for XRF analysis.
R-22 768-773 Hand-picked fragments	This polished thin section contains a pilotaxitic dacitic lava with clinopyroxene phenocrysts up to 0.4 mm in size, sieved and resorbed plagioclase phenocrysts up to 1.2 mm (two populations), and rounded quartz grains up to 0.7 mm with fine-grained pyroxene reaction rims.
R-22 793-798 Hand-picked fragments	This polished thin section contains an olivine-porphyritic basalt with euhedral unaltered olivine phenocrysts up to 0.7 mm in size. Matrix glass is altered to orange-yellow clay; ~1% of the sample consists of calcite-filled vesicles.
R-22 903-908 Hand-picked fragments	This polished thin section contains variants of olivine-porphyritic or mixed-porphyritic basalts. Most fragments have olivine phenocrysts up to ~0.6 mm in size in an intergranular matrix; one fragment also contains coarse (0.8 mm) subophitic clinopyroxene and another fragment consists of an olivine – clinopyroxene – plagioclase porphyritic lava.
R-22 963-968 Hand-picked fragments	This polished thin section contains an olivine-porphyritic basalt with olivine phenocrysts up to 0.4 mm in size and abundant subophitic clinopyroxene of comparable size. Clinopyroxene has brown to red-brown pleochroism.
R-22 1053-1058 Hand-picked fragments	This polished thin section contains an intersertal olivine-porphyritic basalt with subophitic clinopyroxene and minor clay alteration.
R-22 1163-1168 Hand-picked fragments	This polished thin section contains a heavily clay-altered olivine-porphyritic basalt with olivine phenocrysts up to 1 mm in size. The olivine in this sample is almost completely altered to coarse clay aggregates with strong yellow to yellow-brown coloration. Vesicles are completely filled by coarse-grained calcite.
R-22 1188-1191 2- to 4-mm size fraction	This polished thin section contains a heterogeneous mixture of intermediate to siliceous lithologies and one fragment (2%) of intersertal olivine basalt. The intermediate to siliceous lithologies include fragments too heavily altered for accurate petrographic analysis (27%), clinopyroxene-porphyritic lava (12%), lava with clinopyroxene microphenocrysts (8%), amphibole-porphyritic lava (10%), biotite-porphyritic lava (10%), biotite-porphyritic vitric pumice (2%), clinopyroxene-biotite porphyritic lava (8%), clinopyroxene-amphibole porphyritic lava (7%), felsic intermediate lava fragments without phenocrysts (10%), devitrified tuff (2%), and altered pumice (2%).
R-22 1273-1278 2- to 4-mm size fraction	This polished thin section contains a heterogeneous mixture of intermediate to siliceous lithologies with one fragment (2%) of intersertal olivine basalt and one fragment (2%) of muscovite-microcline metagranite. The intermediate to siliceous lithologies include clinopyroxene-porphyritic lava (36%), lava with clinopyroxene microphenocrysts (7%), clinopyroxene-biotite porphyritic lava (14%), clinopyroxene-amphibole porphyritic lava (4%), clinopyroxene-orthopyroxene porphyritic lava (9%), felsic intermediate lava fragments without phenocrysts (7%), lava with relict biotite phenocrysts (4%), lava with relict amphibole phenocrysts (4%), lava with relict orthopyroxene phenocrysts (2%), lava with clinopyroxene and relict olivine phenocrysts (2%), and devitrified tuff with plagioclase phenocrysts (7%).
R-22 1323-1328 2- to 4-mm size fraction	This polished thin section consists predominantly of fragments of immature volcanic sandstone with clay matrix (55% of all fragments). Grains in the volcanic sandstone include plagioclase, clinopyroxene, amphibole, biotite, and glass; in fragments with abundant clay, the clay is orange-brown. In addition to the volcanic sandstone, there are fragments of clinopyroxene-porphyritic lava (18%), clinopyroxene-biotite porphyritic lava (6%), biotite-porphyritic lava (6%), vitric aphyric pumice (6%), and devitrified tuff (6%). There is also one fragment (3%) of a sandstone with plutonic and metamorphic provenance, containing grains of quartz, microcline, muscovite, and plagioclase.

R-22 1347-1352 Hand-picked fragments	This polished thin section contains two textural variants of basaltic lithology: (1) an olivine- and clinopyroxene-porphyritic to subophitic basalt with abundant skeletal magnetite and ilmenite, and (2) an olivine-porphyritic basalt. In both lithologies, the olivine and portions of the matrix are fully altered to yellow-orange, coarse-grained clay, separate green clay in other matrix portions, iddingsite around relict olivines, and possible leucoxene. A subsample of the olivine-porphyritic basalt with unaltered olivine was culled from the cuttings for XRF analysis (column 17, Table 11.3-1).
R-22 1377-1382 Hand-picked fragments	This polished thin section contains fragments of basalt with iddingsite-altered olivine phenocrysts up to 0.5 mm in size, intergranular clinopyroxene up to 0.15 mm in size, and a lath framework of plagioclase grains up to 1 mm. Matrix glass between plagioclase laths has been largely altered to yellow clay.
R-22 1397-1402 Hand-picked fragments	This polished thin section contains fragments similar to those in the sample at 1377- to 1382-ft depth: basalt with iddingsite-altered olivine phenocrysts up to 0.5 mm in size, intergranular clinopyroxene up to 0.15 mm in size, and a lath framework of plagioclase grains up to 1 mm. Matrix glass between plagioclase laths has been largely altered to yellow clay. Darker and lighter subsamples of the cuttings were separated for XRF analysis (columns 19 and 20, Table 11.3-1).
R-22 1412-1417 2- to 4-mm size fraction	This polished thin section contains various fragments of intermediate-composition lava dominated by clinopyroxene-porphyritic dacite (55%). Other fragments of intermediate-composition lava include clinopyroxene-orthopyroxene porphyritic lava (15%), clinopyroxene-amphibole porphyritic lava (5%), and intermediate-composition lavas too heavily altered for accurate petrographic analysis (8%). Rarer fragments include pumice (1%) and olivine basalt (1%); the remainder of the sample (15%) consists of fragments of immature clinopyroxene-rich volcanic sandstone with grains of plagioclase and rarer amphibole, biotite, and glass.
R-22 1447-1452 2- to 4-mm size fraction	This polished thin section contains various fragments of intermediate-composition lava dominated by clinopyroxene-porphyritic dacite (45%). Other fragments of intermediate-composition lava include clinopyroxene-orthopyroxene porphyritic lava (2%), clinopyroxene-amphibole porphyritic lava (2%), clinopyroxene-biotite porphyritic lava (2%), biotite-porphyritic lava (7%), vitric pumice (12%), and intermediate-composition lavas too heavily altered for accurate petrographic analysis (14%). The remainder of the sample (16%) consists of fragments of immature clinopyroxene-rich volcanic sandstone with grains of plagioclase and rarer amphibole, biotite, and glass.
R-22 1452-1457 Hand-picked fragments	This polished thin section contains a variety of partially clay-altered intermediate-composition pumices. Commonest phenocrysts in the pumices are plagioclase and biotite, with less common clinopyroxene phenocrysts and apatite microphenocrysts.
R-22 1482-1487 2- to 4-mm size fraction	This polished thin section contains various fragments of intermediate-composition lava including clinopyroxene-porphyritic dacite (27%), clinopyroxene-orthopyroxene porphyritic lava (8%), amphibole-porphyritic dacite (5%), intermediate-composition lavas too heavily altered for accurate petrographic analysis (12%), vitric pumices of intermediate-composition lava (12%), and altered pumices of intermediate-composition lava (15%). There is also one fragment (2%) of olivine basalt, and there are 3 fragments (5%) of metamorphic siliceous lithologies (a biotite-muscovite metagranite, a kyanite quartzite, and a strained quartz grain of metamorphic origin).